Addressing Vapor Intrusion at Remediation & Redevelopment Sites in Wisconsin
Wis. Stat. ch. 292; Wis. Admin. Code ch. NR 700

Purpose

The purpose of this guidance is to provide approaches for complying with the requirements in Wis. Stat.ch. 292 and Wis. Admin. Code ch. NR 700 that relate to vapor intrusion. This guidance identifies the conditions where assessment of the vapor intrusion pathway is necessary at contaminated sites; sets out the criteria for evaluating health risk; identifies appropriate responses; explains long-term stewardship; and clarifies when sites with a complete or potential vapor migration pathway may achieve closure.

This guidance is applicable to contaminated sites where volatilization of subsurface contaminants has migrated or has the potential to migrate to current or future occupied buildings. Unless otherwise noted, all provisions in this guidance apply to the responsible party (RP) and/or property owner of a contaminated site.

Related DNR Guidance

- RR-042: DNR Case Closure Continuing Obligations: Vapor Intrusion
- RR-986: Sub-slab Vapor Sampling Procedures

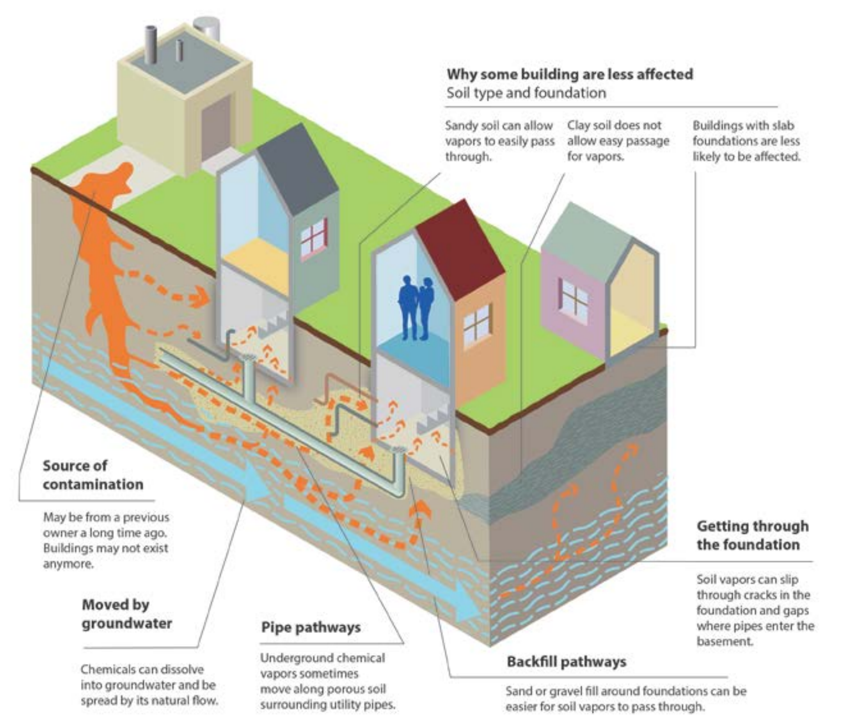
Related DNR Factsheets

- RR-067: Vapor Intrusion Investigation - Information Sheet for Neighbors
- RR-892: What is Vapor Intrusion
- RR-953: Why Test for Vapor Intrusion?
- RR-954: What to Expect During Vapor Intrusion Sampling
- RR-977: Understanding Chemical Vapor Intrusion Testing Results
- RR-934: Who Should I Contact About Vapor Intrusion Investigations?
- RR-973: Environmental Contamination & Your Real Estate

Overview of Vapor Intrusion

Vapor intrusion generally refers to subsurface contamination that can volatilize and the vapors enter the breathing space of buildings. Vapor intrusion can also occur when contaminated groundwater infiltrates buildings and contaminants directly volatilize into the indoor air. Vapors can migrate through air space in permeable soils, fractures in bedrock or clay tills, utilities, sumps, or cracks in the building foundation.

How vapor intrusion happens: **a complex path**



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List of acronyms

AARST	American Association of Radon Scientists and Technologists
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineering
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CVOC	Chlorinated Volatile Organic Compound
DHS	Department of Health Services
DNR	Department of Natural Resources
ESTCP	Environmental Security Technology Certification Program (Department of Defense)
HI	Hazard Index
HVAC	Heating, Ventilation, and Air Conditioning
ITRC	Interstate Technology Regulatory Council
LEL	Lower Explosive Limit
NAPL	Non-Aqueous Phase Liquids
NAVFAC	Naval Facilities Engineering Command
NR	Natural Resources
OM&M	Operation, Monitoring, & Maintenance
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid waste and Emergency Response
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PCE	Tetrachloroethene
PFE	Pressure Field Extension
PID	Photoionization Detector
PVOC	Petroleum Volatile Organic Compound
QA/QC	Quality Assurance/Quality Control
RP	Responsible Party
TCE	Trichloroethene
TPH	Total Petroleum Hydrocarbons
U.S.EPA	United States Environmental Protection Agency
UST	Underground Storage Tank
VAL	Vapor Action Level
VRSL	Vapor Risk Screening Level
VOC	Volatile Organic Compound

1 INTRODUCTION

1.1 PURPOSE, SCOPE, AND APPLICABILITY

The purpose of this guidance is to provide approaches for complying with the requirements in Wis. Stat. ch. 292 and Wis. Admin. Code ch. NR 700 that relate to vapor intrusion. This guidance incorporates the October 2013 updates to Wis. Admin. Code ch. NR 700. This guidance identifies the conditions where assessment of the vapor intrusion pathway is necessary at contaminated sites[1]; sets out the criteria for evaluating health risk; identifies appropriate responses; explains long-term stewardship; and clarifies when sites with a complete or potential vapor migration pathway may achieve closure. Anyone addressing discharge of hazardous substance or environmental pollution under Wis. Stat. ch. 292 must also comply with the Wis. Admin. Code ch. NR 700 rule series, including assessment and remediation of all pathways of concern.

This guidance is applicable to contaminated sites where volatilization of subsurface contaminants has migrated or has the potential to migrate to current or future occupied buildings. It is intended to provide the responsible party (RP) and/or property owner of a contaminated site the information needed to satisfy the legal requirements related to vapor intrusion in Wis. Stat. ch. 292 and Wis. Admin. Code ch. NR 700. *Other site-specific approaches can also be used if they meet the applicable requirements in state law.*

For sites or facilities where overlapping statutory restrictions or requirements are applicable, the more restrictive shall control as per Wis. Admin. Code § NR 700.02(3m).

1.2 OVERVIEW OF VAPOR INTRUSION

Vapor intrusion generally refers to subsurface contamination that can volatilize and the vapors enter the breathing space of buildings. Vapor intrusion can also occur when contaminated groundwater infiltrates buildings and contaminants directly volatilize from the groundwater into indoor air of the building. Vapors may migrate through air space in permeable soils, fractures in bedrock or clay tills, man-made utility structures, basement sumps, cracks in the building foundation, or other mechanisms.

1.3 WHAT CHEMICALS DOES THIS GUIDANCE ADDRESS?

A vapor intrusion assessment is only required for those contaminants that are considered sufficiently volatile and toxic to be a risk through the vapor pathway (see **Section 3.1**). Chlorinated volatile organic compounds (CVOC) and petroleum volatile organic compounds (PVOCs) are the contaminants that most commonly result in the need to assess the vapor intrusion pathway at contaminated sites, and are specifically addressed in this guidance.

Depending upon site conditions, semi-volatile contaminants (such as PAHs, dioxins, PCBs, etc.), mercury (a volatile metal), or methane generated by contaminant degradation may also present a risk of vapor intrusion. If vapor intrusion from these compounds is suspected at a contaminated site, specific screening and investigation methods should be discussed with the Wisconsin Department of Natural Resources (DNR) Project Manager.

Many of the same principles used to evaluate and mitigate radon gas intrusion in buildings also apply to vapor intrusion. However, radon gas is *not* addressed by this guidance.

[1] Contaminated sites refers to those sites and facilities that are subject to regulation under Wis. Stat. chs. 289 and 292.

1.4 REFERENCES AND OTHER GUIDANCE

For information on vapor intrusion topics that go beyond the scope and detail in this guidance, readers are referred to publications by the United States Environmental Protection Agency (U.S. EPA)[2], Interstate Technology Regulatory Council (ITRC)[3], and other guidance documents listed in the footnotes and references section.

1.5 OTHER DNR PUBLICATIONS

The DNR also has other publications available on vapor intrusion. These documents can be found on http://dnr.wi.gov/topic/Brownfields/Vapor.html or by searching for the publication number on the guidance index http://dnr.wi.gov/topic/Brownfields/Pubs.html. These additional publications include:

Guidance

- RR-042: DNR Case Closure Continuing Obligations: Vapor Intrusion
- RR-986: Sub-slab Vapor Sampling Procedures

Factsheets

- RR-067: Vapor Intrusion Investigation- Information Sheet for Neighbors
- RR-892: What is Vapor Intrusion
- RR-953: Why Test for Vapor Intrusion?
- RR-954: What to Expect During Vapor Intrusion Sampling
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- RR-934: Who Should I Contact About Vapor Intrusion Investigations?
- RR-973: Environmental Contamination & Your Real Estate

Templates

- RR-956/957: First/Second Request for Access to Sample for Vapor Intrusion
- RR-976: Access Agreement to Sample for Vapor Intrusion
- RR-960: Vapor Intrusion Sample Results No Detection
- RR-961: Vapor Intrusion Sample Results Below Screening Level
- RR-962: Vapor Intrusion Sample Results Above Screening Level
- RR-959/985: First/Second Request for Vapor Intrusion Mitigation System Installation
- RR-984: Access Agreement to Installation of Vapor Intrusion Mitigation System

Videos

- Vapor Intrusion 101
- The Responsible Neighbor, A Vapor Intrusion Story

[2] U.S. EPA. 2015a. OSWER Technical guide for assessing and mitigating the vapor intrusion pathway from subsurface vapor sources to indoor air. OSWER Publication 9200.2-154. June 2015

[3] ITRC, 2007. *Vapor intrusion pathway: a practical guideline*. Interstate Technology & Regulatory Council. January 2007

2 FRAMEWORK AND DELIVERABLES

Where there has been a discharge to the environment, steps must be taken under Wis. Admin. Code ch. NR 700 to adequately address sources of contamination; and, establish that people are protected from exposure to contamination now and into the future. The guiding framework for assessing the vapor pathway under ch. NR 700 is summarized in **Table 2a**, and the deliverables[4] required during this process are summarized in **Table 2b**.

TABLE 2a
FRAMEWORK FOR VAPOR INTRUSION ASSESSMENTS IN WISCONSIN

Step 1: Vapor Screening	(Wis. Admin. Code § NR 716.07)
Evaluate site conditions and contaminants to determine if vapor intrusion is possible. This technical evaluation is described in Section 3 of this guidance, and may be an iterative process as data becomes available during the site investigation.	
Step 2: Vapor Investigation	(Wis. Admin. Code § 716)
If the possibility of vapor intrusion cannot be ruled out through screening, then the vapor intrusion pathway must be investigated as part of the site investigation. For a vapor investigation, Wis. Admin. Code § NR 716.11(5) requires: ▪ *Sub-slab sampling* to determine the presence and concentration of vapors below occupied buildings[5], and additional sampling as needed to define the extent of subsurface vapor migration. ▪ *Indoor air sampling* when needed to determine the impact vapor intrusion has on occupied structures. (When subsurface concentrations meet or exceed vapor risk screening levels, indoor air sampling is expected for residential[6] buildings and for most non-residential buildings if the contaminant of concern is no longer in use.)	
Step 3: Mitigation of Exposure to Vapor Intrusion	(Wis. Admin. Code §§ NR 708 and 722)
If the results from sub-slab vapor samples are at or over vapor risk screening levels, then interruption or mitigation of the vapor exposure pathway is required per Wis. Admin § NR 726.05. The level of response and approach to mitigation will depend on the site conditions, land use, and indoor air results. Vapor mitigation is generally considered an interim action under Wis. Admin. Code § NR 708, which means it can be done before or after the site investigation is complete, and satisfy to the requirements of Wis. Admin. Code § NR 724 (design, performance verification, and operation and maintenance).	
Step 4: Remediation of the Vapor Source	(Wis. Admin. Code §§ NR 722 and 724)
When subsurface vapors are at or over vapor risk screening levels, then Wis. Admin. Code §§ NR 722.09 and 726.05 require remedial action to reduce the mass and concentration of the vapor source, to the extent practicable. Remedial action is done after the site investigation is complete, and selection of the remedial action will address other site conditions and clean up criteria.	
Step 5: Long-Term Protection From Vapor Intrusion	(Wis. Admin. Code § NR 724)
To ensure vapor mitigation remains effective as long as it is needed, a long-term operation, monitoring and maintenance (OM&M) plan is required per Wis. Admin. Code § NR 724.13. The long-term OM&M is the responsibility of the RP until closure, and becomes the responsibly of the property owner after closure. The OM&M plan should be prepared to meet the needs of these end users. A copy of the OM&M plan should be provided to each property owner prior to closure.	
Outreach and Communication (Steps 2 – 5)	(Wis. Admin. Code §§ NR 714, 716, and 725)
The overall goal is to protect people from exposure to vapor intrusion. This effort often requires access permissions and work on properties not owned by the RP. Good, communications with owners and occupants is essential to accomplishing the public health goal. At a minimum this communication includes: ▪ Providing the required Wis. Admin. Code § NR 714 notifications and a making best faith effort to gain access; ▪ Providing sample results to property owners/occupants within 10 business days, Wis. Admin. Code § NR 716.14; ▪ Explaining long-term OM&M responsibilities for vapor mitigation to owners, Wis. Admin. Code § NR 725.	

[4] See RR-690 – *Guidance for Electronic Submittals* and RR-971– *Proper Submittal of Documents and Requests for Assistance*
[5] For properties without buildings, then sub-slab vapor sampling may be required after a building is constructed.
[6] A residential setting may include single or multiple family housing, and educational, childcare, and elder care facilities.

TABLE 2b
DELIVERABLES REQUIRED IN A VAPOR ASSESSMENT

DNR will review and provide written response to the RP for deliverables submitted with the appropriate review fee, per Wis. Admin. Code § NR 749. Unless otherwise directed, the RP must submit these deliverables regardless of whether a review fee is provided.

ITEM	WIS. ADMIN. CODE § NR	SUMMARY
Site Investigation Scope and Work Plan	716.07 716.09	Submit intended scope of investigation to DNR within 60 days from RP letter. ▪ Use vapor screening (**Sections 3)** to help scope the site investigation (**Section 5**). ▪ Include a summary of the results of vapor screening to justify the proposed scope or explain why a vapor investigation is not needed. DNR recognizes that this may be iterative process.
Notification to Affected Property Owners	714.07	Provide information to property owners where access is needed to complete a vapor investigation, install vapor mitigation, or where there is a high level of public concern. ▪ See http://dnr.wi.gov/topic/Brownfields/Vapor.html for model template letters and fact sheets on vapor intrusion. ▪ Provide DNR a copy of letters and a summary of other communications as needed to document best faith efforts to gain access (see **Section 4**). DNR recognizes communication may be needed throughout a vapor assessment and the approaches and effort will vary based on circumstances.
Notification of Sampling Results	716.14	Provide a copy of vapor sampling data within 10 business days from receiving the sample results (the department may approve a different notification schedule on a case-by-case basis.). ▪ Provide DNR all data and include a preliminary analysis of the cause of any significant detections and summary of who else is receiving the data. ▪ Provide property owners, and occupants as appropriate, the results for samples collected on their property. The transmittal of sampling results to affected property owners must be accompanied by a letter or department form that gives context to the information. See Wis. Admin. Code § NR 716.14(2)(c) and the template letters at http://dnr.wi.gov/topic/Brownfields/Vapor.html for more information on what to include in these transmittals.
Immediate or Interim Action Plans and Reports *(i.e. Vapor Mitigation)*	708.05 708.11 708.15	Evaluate the need for immediate or interim action to mitigate exposure to vapors during the site investigation (see **Section 7**). Wis. Admin. Code § NR 708 immediate and interim actions must be initiated when an evaluation shows they are necessary, which may be before the site investigation is complete. For residential buildings, immediate or interim actions will typically be the design, installation, and performance verification of a sub-slab depressurization system to mitigate vapor intrusion (see **Section 8**). Documentation is required after work is complete: ▪ *Immediate action*: Provide documentation of any immediate actions taken to mitigate exposure to vapors within 45 days after notification of the discharge. ▪ *Interim action*: Provide DNR design and implementation plans for the engineering control selected to mitigate exposure to vapors; and include documentation in either the site investigation report, the remedial action report, or a separate submittal for the interim action (see Wis. Admin. Code § NR 724 requirements listed below in this Table).

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ITEM	WIS. ADMIN. CODE § NR	SUMMARY
Site Investigation Report	716.15	Summarize the results of the vapor investigation in the site investigation report within 60 days after completion of the site field investigation and receipt of all laboratory data. ▪ *Scope*: Summarize the data and conclusions from the vapor screening. Use this analysis to justify the scope of the vapor investigation or explain why a vapor investigation was not needed (see **Section 3**). ▪ *Methods*: Describe the vapor sampling and quality control methods. (see **Section 5**) ▪ *Tables*: Compile all the vapor sampling results in data tables, which identify the sample location and compare the results to the appropriate risk screening levels (see **Section 6**). ▪ *Maps*: Show all vapor sampling locations and results on site maps and identify sample locations where the results were over risk screening levels. Distinguish between soil gas, sub-slab, indoor air, or other types of vapor samples. ▪ *Cross-Sections*: Include vapor results in cross-sections with the site stratigraphy and water levels. Viewing the depth where vapor samples were collected, the elevation of a building's foundation, and how these relate to the site conditions and contaminant distribution will often help in the interpretation of sampling results, which is required in the site investigation report. ▪ *Photographs*: Include photographs, as needed, to show the site conditions at sampling locations (e.g. well-maintained and large space industrial building vs. a run-down building with small interior spaces and cracks in the foundation). ▪ *Interpretation*: Use the data on the geology, preferential pathways, building location, and contaminant distribution to evaluate the vapor sampling results and demonstrate that the extent of vapor impacts has been delineated for the site.
Remedial Action Options Report	722.09 722.13	Submit a remedial actions option report to DNR within 60 days of the site investigation report (see **Section 7**). ▪ Include the vapor pathway in the criteria to select a remedial action for a site. ▪ DNR can require vapor control technologies as a condition of approval of the remedial action. *Vapor mitigation is an interim action* and is *not* equivalent to remediation. Remedial actions are implemented to reduce the mass and concentration of the source of vapors, which is required to achieve closure when vapor concentrations met or exceeded vapor risk screening levels – Wis. Admin. Code § NR 726.05(8).
Design Report and Plans *(Remedial & Interim Actions)*	724.09 724.11	Provide design plans and specifications to the DNR for *each* remedial action and interim action selected for a site (see **Section 8**). ▪ *Schedule:* Tell DNR proposed dates for starting and completing the work. ▪ *Performance Verification Plan:* Include a preliminary plan for how to show that the design meets performance criteria. ▪ *OM&M Plan:* Provide preliminary discussion on planned operation and maintenance. *For vapor mitigation,* the content requirements for plans are the same, but the plans may be submitted before the site investigation is complete (see Wis. Admin. Code § NR 708 above).

TABLE 2b
DELIVERABLES REQUIRED IN A VAPOR ASSESSMENT

DNR will review and provide written response to the RP for deliverables submitted with the appropriate review fee, per Wis. Admin. Code § NR 749. Unless otherwise directed, the RP must submit these deliverables regardless of whether a review fee is provided.

ITEM	WIS. ADMIN. CODE § NR	SUMMARY
Construction Documentation Reports *(Remedial & Interim Actions)*	724.15	Provide a documentation report to the DNR for any remedial or interim action (vapor mitigation) within 60 days after construction is complete. ▪ *Performance Verification:* Document that the final action meets design criteria. ▪ *As Built Conditions:* Document the baseline conditions that meet the design criteria. *For vapor mitigation*, construction documentation is also call the commissioning phase. Construction is considered complete after performance is verified and documentation is provided to the DNR (see **Section 9**).
OM&M Plans *(Remedial & Interim Actions)*	724.13 724.17	Submit a copy of the OM&M report to the DNR when one is needed to ensure the effectiveness of a remedial or interim action (see **Section 10**). *For vapor mitigation*, an OM&M Plan: ▪ Is required for *each property* where mitigation is installed; ▪ Is expected to be put in place *after commissioning* is complete; ▪ Will become the *responsibility of the property owner* after DNR approves case closure, and so the plan should be prepared with this end user in mind.
Notification of Continuing Obligations	725.05 726.11 726.13	At least 30 days prior to submitting a case for closure, notify owners that they will become responsible for maintaining the vapor mitigation system, or other conditions needed to ensure continued protection from exposure to vapors (see **Section 11**). ▪ Provide owner/occupants with a copy of the OM&M plan. ▪ Provide DNR a copy of the notification and certification of receipt or the notice. ▪ Provide DNR a copy of any legal agreements made between the RP and property owner(s) that obligates another person to maintain a continuing obligation. * *When vapor mitigation* is installed on an off-site property, it is recommended that this notification be discussed with property owner closer to the time that the system is commissioned, rather than the minimum 30 days leading up to closure.
Closure	726.08 726.09	If requesting case closure, provide DNR with the data and evaluation that demonstrates exposure to vapors is prevented now, and site conditions will remain protective in the future. ▪ *Screening*: Summarize information used in the vapor screening. Justify the scope of the vapor investigation or explain why vapor sampling was not needed. ▪ *Data:* Summarize all the vapor sampling results (site investigation, post-remediation, and performance verification), and compare to appropriate vapor screening levels. ▪ *Interim or Immediate Actions*: Describe and show where interim or immediate actions were completed to mitigate exposure from vapor intrusion. Include performance verification that documents the effectiveness. ▪ *Remedial Action:* Summarize the remedial actions taken to reduce the mass and concentration of the vapor source or provide justification for no remedial action. ▪ *Long-term OM&M for Vapor Mitigation:* Provide DNR copy of maintenance plans for each mitigation system. The OM&M plan should include the information needed to keep the system functioning to level that meets or exceeds design criteria. ▪ *Continuing Obligations:* List and show properties where continuing obligations are needed for continued protection from exposure to vapors.

3 VAPOR INTRUSION SCREENING

Vapor intrusion screening is the first step in a vapor intrusion assessment. Screening uses site-specific information, such as; contaminant type, concentrations, preferential pathways, and distances from receptors to determine whether vapor intrusion is *possible* on or off a contaminated site.

The data and results from vapor intrusion screening are provided to the DNR as the justification for why a vapor investigation is *not* needed or as the basis for the scope of a vapor investigation at a site, as per Wis. Admin. Code § NR 716.11(5)(g).

3.1 IS A CHEMICAL A VAPOR RISK?

Only those chemicals that are considered to be sufficiently volatile (Henry's Law constant > 10^{-5} atm m^3 mol^{-1} or vapor pressure > 1 mm Hg) and toxic (based on inhalation toxicity data) are a potential vapor intrusion risk. Readers are referred to the U.S. EPA's Vapor Intrusion Screening Level Calculator, https://www.epa.gov/vaporintrusion/vapor-intrusion-screening-levels-visls, to determine if the contaminants of concern at a site are sufficiently volatile and toxic to pose an inhalation risk from vapor intrusion. The U.S. EPA's calculator includes "yes" and "no" determinations on this question of vapor risk for over 700 chemicals.

If the contaminant of concern is not sufficiently volatile and toxic to be inhalation risk from vapor intrusion, then provide this information as the technical explanation to the DNR for why a vapor investigation is not needed at a site.

3.2 SCREENING DATA AND DRAWINGS

If contaminants of concern are a potential vapor intrusion risk, then assimilating site data into conceptual drawings and/or cross-sections is recommended for vapor intrusion screening at most sites. Drawings can:

- concisely communicate screening criteria,
- draw attention to data gaps or areas of potential concern,
- be used to scope a vapor investigation, and
- be used and revisited to interpret vapor sampling results.

These drawings do not need to be complex graphics, but should focus on accurate spatial display of site information used to screen for the vapor intrusion pathway.

Site information that may be used to screen for the vapor intrusion pathway includes:

CONTAMINATION	GEOLOGY	BUILDING / INFRASTRUCTURE
▪ Volatile Contaminant Type(s) (PVOC vs. CVOC) ▪ Soil Impacts in Vadose Zone (concentration & depth) ▪ Groundwater Table Impacts (concentration & depth) ▪ NAPL Indicators (concentration & depth)	▪ Depth to Groundwater ▪ Soil Type(s) in Vadose Zone (permeable vs. impermeable) ▪ Depth of Vadose Zone Soils ▪ Aerated Soil Indicators (PVOC only) ▪ Fractures (bedrock or clay)	▪ Distance from Contamination (lateral & vertical) ▪ Foundation Specifications (depth, material, thickness) ▪ Foundation Condition (cracks, transitions, openings) ▪ Utilities (current and historical) ▪ Sumps ▪ Petroleum Odors Indoors

3.3 PREFERENTIAL PATHWAYS & FACTORS AFFECTING SCREENING GUIDELINES

Vapors have the potential to migrate along preferential flow pathways in the subsurface (e.g. sewer lines, bedrock fractures, or utility corridors[7]). These preferential pathways can have a strong effect on movement and accumulation of contaminated vapors to indoor air. *Screening should include evaluation of preferential pathways, especially at sites where volatile contaminants could have been disposed into sewer lines via floor drains, sinks, toilets, sumps, or storm grates.*

Vapor migration is also affected by factors such as soil type, soil moisture, water level variation, extent of the groundwater plume, age of discharge, etc. The screening guidelines listed below in **Figures 3a and 3b** can be used to identify buildings where site conditions trigger the need for sub-slab vapor sampling, per Wis. Admin. Code § NR 716.11(5)(g). However, these are only guidelines, and the actual distances may vary based on site-specific conditions.

3.4 SCREENING FOR CHLORINATED VOCs

CVOCs do not degrade in vadose zone soils and tend to migrate long distances from the source of contamination. The most common CVOCs presenting a vapor risk at contaminated sites are tetrachloroethene (PCE) and trichloroethene (TCE). Vapors from these chemicals are toxic at low concentrations that cannot be detected by their odor. *Therefore, it is rare to be able to rule out vapor intrusion in the screening phase when a site is contaminated with CVOCs.*

3.4.1 TCE – Potential Need to Prioritize Action

For most contaminants, vapor risks are based on chronic long-term exposure[8]. However, for TCE, there is a possible acute (short-term) risk of fetal heart malformation that may occur when a pregnant mother is exposed to TCE vapors in the first trimester of pregnancy[9].

When TCE is a contaminant of concern, the demographics of potential receptors should be determined as soon as possible, and sampling at homes/locations with women of child bearing age that are within the screening distances, should be made a priority. In most cases, sampling should be done as soon as possible, but the urgency for sampling will be determined on a case-by-case basis depending on circumstances. State and/or local health officials should be made aware of the situation and can provide assistance if needed with evaluating and communicating risk.

3.4.2 CVOC Screening Guidelines

Groundwater can carry dissolved phase CVOCs over long distances. When this contamination is at the water table, the CVOCs can volatilize off the groundwater into the vadose zone. Once in vadose zone soils, CVOC vapors do not readily degrade. Consequently, a vapor intrusion investigation is often required at properties downgradient and along other preferential pathways (e.g. utility lines) from the CVOC sources.

Based on the mobility, persistence, and toxicity of CVOC vapors, the DNR expects investigation of the vapor intrusion pathway at contaminated sites in Wisconsin that meet one or more of the screening distances listed in **Figure 3a.** *If other site-specific conditions are used, then provide these data and evaluation to the DNR as the basis for why sub-slab vapor sampling is not needed at a particular building.*

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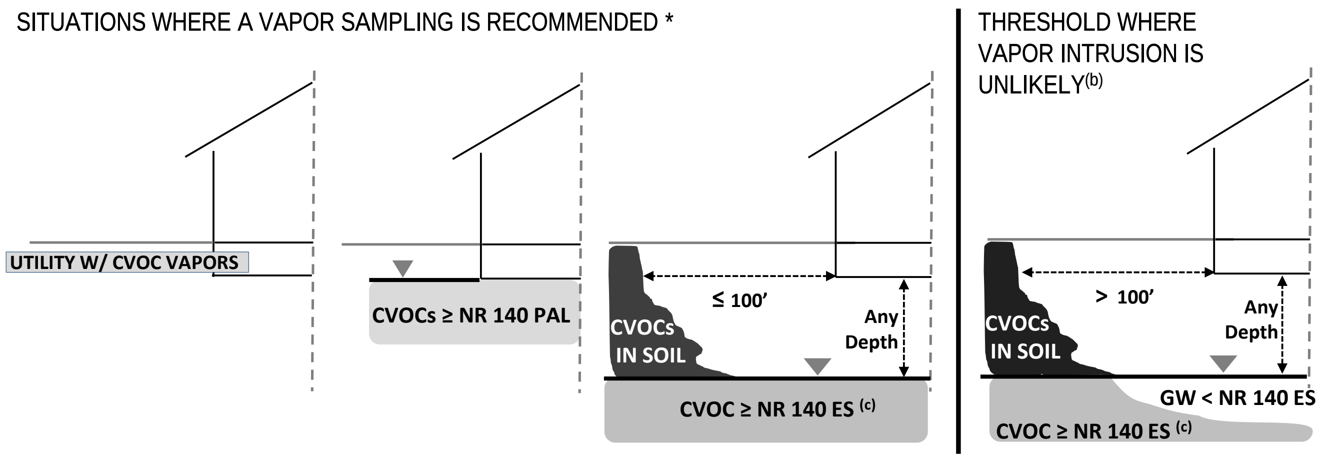
[7] See the DNR's "Guidance for Documenting the Investigation of Utility Corridors", http://dnr.wi.gov/files/PDF/pubs/rr/RR649.pdf

[8] Acute and immediate risks may be present in situations where contaminant vapors are found in indoor air at very high concentrations.

[9] U.S. EPA 2014a. EPA Region 9 Response Action Levels and Recommendations to Address Near-Term Inhalation Exposures to TCE in Air from Subsurface Vapor Intrusion. July 9, 2014.

FIGURE 3a
CVOC VAPOR INTRUSION SCREENING GUIDELINES



* Per Wis. Admin. Code § NR 716.11(5)(g), sub-slab vapor sampling is required when soil, soil gas, or groundwater indicates vapor may migrate to the foundation of an occupied building. Generally, these recommended guidelines will trigger the need for sampling. However, other site-specific conditions are permissible in this evaluation. Provide the technical data and evaluation to the DNR as the basis for why sub-slab vapor sampling is not needed at a particular building.

PARAMETER	VAPOR INVESTIGATION RECOMMENDED IF…
Soil	Building[(a)] over or within 100 feet[10] of CVOC impacted soil.
Groundwater *(Below foundation)*	Building[(a)] overlies groundwater with CVOC concentrations above Wis. Admin. Code § NR 140 Enforcement Standards (ES) at the water table[(b) (c)].
Groundwater *(Contacts foundation)*	Groundwater with concentrations above Wis. Admin. Code § NR 140 Preventive Action Limit (PAL) has entered the building or is in contact with the building's foundation.
Preferential Pathways	Utility line(s) that transect a CVOC source area.

(a) Criteria also apply to undeveloped properties that do not currently have buildings.
(b) When groundwater contamination is deep and the water table is clean, the clean water prevents the migration of vapors into the vadose zone. Vapor intrusion is not a risk from the contaminated groundwater in that scenario.
(c) The NR 140 ES criteria applies to PCE and TCE. For other CVOCs, the groundwater concentration posing a potential vapor risk can be calculated using the equation in **Table 6a**.

[10] Lowell, P.S. and B. Eklund. 2004. VOC Emission Fluxes as a Function of Lateral Distance from the Source, Environmental Progress, Vol. 23, No. 1, April 2004.

3.5 SCREENING FOR PETROLEUM VOCs

Vapor migration from PVOCs is fundamentally different than vapor migration from CVOCs. Unlike vapors from chlorinated compounds, vapors from petroleum hydrocarbons will rapidly biodegrade in unsaturated vadose zone soils. *This biodegradation is predictable and allows vapor intrusion to frequently be ruled out for PVOCs in the screening phase.*

3.5.1 Sites Where PVOC Screening Applies

The PVOC screening guidelines apply to a wide variety of sites that include, but are not limited to:

- Gas Stations (gasoline and diesel)
- Heating Oil USTs
- Refineries and Bulk Storage Facilities
- Former Manufactured Gas Plants
- Creosote Facilities
- Dry Cleaners Using *Only* Petroleum Solvents

3.5.2 Potential for Explosive Conditions

High concentration of petroleum vapors can create an explosion risk. Explosion hazards are most often associated with a new discharge of petroleum compounds to the environment. Responders to hazardous spills and local fire departments can assist in evaluating explosion risk in those situations. Measuring the Lower Explosive Limit (LEL) in soil gas and/or indoor air can be used to evaluate an explosion hazard. Depending on the results, an appropriate immediate or interim action must be taken to eliminate the explosion hazard in accordance with Wis. Admin. Code § NR 708.

3.5.3 PVOC Screening Guidelines

Because vapor migration from PVOCs differs significantly from CVOCs, ITRC[11] and the U.S. EPA[12] have prepared vapor intrusion guidance documents specific to PVOCs. Empirical data presented in these and other guidance demonstrate that vapor intrusion from PVOCs occurs far less frequently than vapor intrusion from CVOCs. Vapor intrusion from PVOCs most often occurs when petroleum non-aqueous phase liquid (NAPL) is located near a building foundation, when petroleum contaminated groundwater is in contact with a building foundation, or when the discharge of a petroleum substance recently occurred.

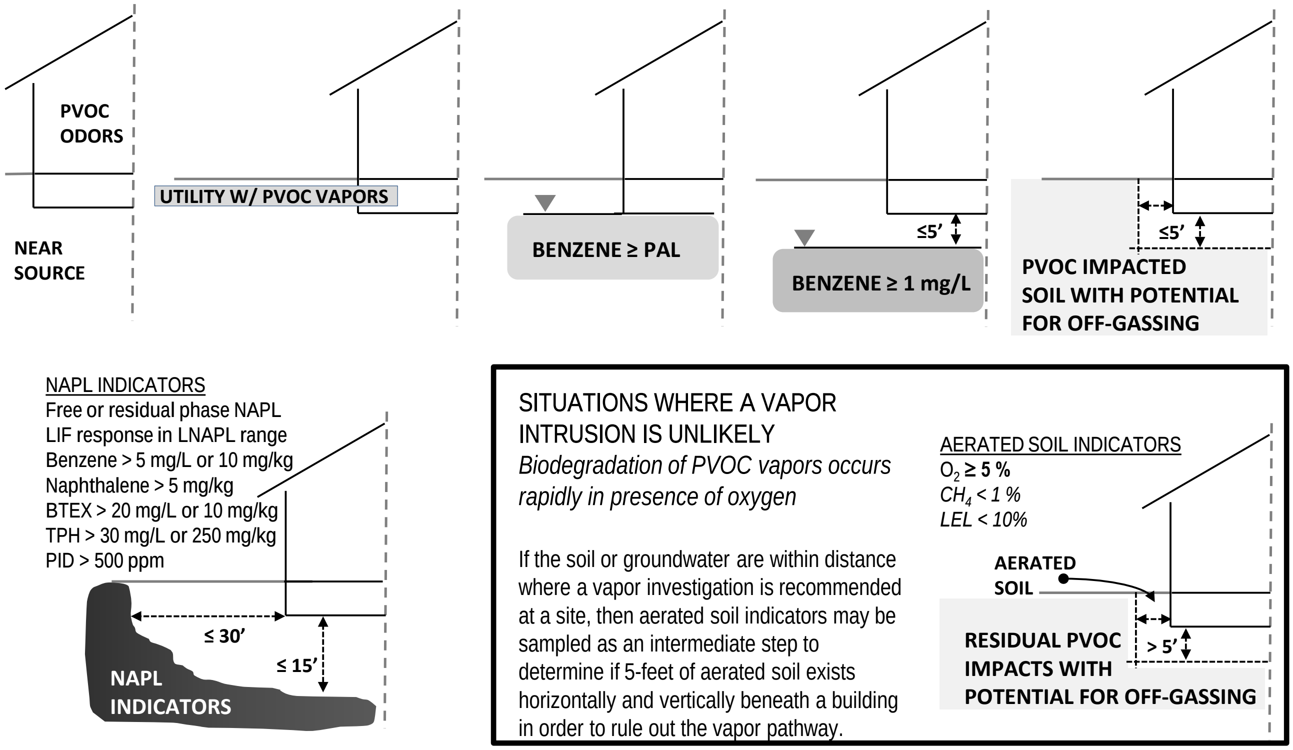
Because petroleum vapors biodegrade rapidly in aerated soils, the DNR allows vapor intrusion to be ruled out if aerated soil conditions (high O_2 and low CH_4, CO_2 and LEL) can be confirmed in the zone within 5-feet horizontally and vertically beneath a building. *Testing for aerated soil conditions exists can be completed as an intermediate step to rule out the vapor pathway.*

The DNR expects investigation of the vapor intrusion pathway for PVOCs at contaminated sites in Wisconsin that meet one or more of the screening distances in **Figure 3b.** *If other site-specific conditions are used, then provide these data and evaluation to the DNR as the basis for why sub-slab vapor sampling is not needed at a particular building.*

[11] ITRC, 2014. Petroleum Vapor Intrusion: Fundamentals of Screening, Investigation, and Management. PVI-1. Washington, D.C.: Interstate Technology & Regulatory Council, Petroleum Vapor Intrusion Team. October 2014.
[12] U.S. EPA. 2015b. Technical Guidance for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites. EPA-510-R-15-001. Washington, D.C. U.S. Environmental Protection Agency Office of Underground Storage Tanks. June 2015.

FIGURE 3b
PVOC VAPOR INTRUSION SCREENING GUIDELINES

SITUATIONS WHERE A VAPOR INVESTIGATION IS RECOMMENDED *



* Per Wis. Admin. Code § NR 716.11(5)(g), sub-slab vapor sampling is required when soil, soil gas, or groundwater indicates vapor may migrate to the foundation of an occupied building. Generally, these recommended guidelines will trigger the need for sampling. However, other site-specific conditions are permissible in this evaluation. Provide the technical data and evaluation to the DNR as the basis for why sub-slab vapor sampling is not needed at a particular building.

** NOTE **

If the soil and groundwater distances listed below are present at a site, testing to determine if 5-feet of aerated soil conditions exists horizontally and vertically beneath a building can be completed as an intermediate step to rule out the vapor pathway.

PARAMETER	VAPOR INVESTIGATION RECOMMENDED IF…
NAPL	Building has less than 15-feet vertical separation[(a)] or 30-feet horizontal separation from NAPL (see NAPL INDICATORS[(b)]).
Groundwater (Below foundation)	Building has less than 5-feet of vertical separation[(a)] from groundwater with benzene > 1 mg/L.
Groundwater (Contacts foundation)	Groundwater with concentrations above Wis. Admin. Code § NR 140 PAL has entered the building or is in contact with the building's foundation.
Soil	Building has less than 5-foot (vertical[(a)] and horizontal) separation distance from petroleum contaminated soil with the potential for off-gassing[(c)].
Preferential Pathway	Petroleum vapors are present in utilities that transect a petroleum source area.
Odors	Petroleum odors are present in building near petroleum source area.

(a) Vertical separation is distance between lowest point of building (e.g. crawl space, basement, foundation) and the contaminant.
(b) Naphthalene screening level based on the non-industrial direct contact soil RCL, but NAPL may exist at lower concentrations.
(c) This includes light end distillates (e.g. gasoline). Heavier end petroleum products (e.g. diesel or fuel oil) or heavily weathered light end distillates that no longer contain compounds that are detectable by TO-15 analysis are not likely to be a source of vapors.

4 OUTREACH AND COMMUNICATION

The primary goal of a vapor assessment is to ensure human receptors are protected from the vapor intrusion pathway. When investigation or mitigation of the vapor intrusion pathway are necessary on properties not owned or maintained by the RP, early and effective communication with the owners and occupants of these properties is critical to achieving the goal - protecting them from vapor intrusion exposure.

The Responsible Neighbor, A Vapor Intrusion Story

Watch video to see the benefits of proactive communication with neighbors

Find video at:
http://dnr.wi.gov/topic/Brownfields/VaporPublic.html

4.1 REQUIRED NOTIFICATIONS

There are several situations that require notification to members of the public that may be directly or indirectly affected by discharge of hazardous substances, which are summarized in **Table 4a.**

TABLE 4a
REQUIRED NOTIFICATIONS TO PUBLIC

WIS. ADMIN. CODE § NR	DESCRIPTION
714.07	Provide *introductory information* about the contamination, response actions, and persons to contact: ▪ to owners and occupants of properties where there is potential for vapor intrusion ▪ to other neighboring properties depending on the level of public concern
716.14	Provide *sampling results within 10 business days* of receiving sample results to owners and occupants, as appropriate, of properties where samples were collected. (The department may approve a different notification schedule on a case-by-case basis.)
725.05	Provide information on *operation, monitoring, and maintenance* required to prevent vapor intrusion when residual contamination poses a vapor intrusion risk, and one or more of the *continuing obligations* listed in Section 11 will be assigned to the property.

4.2 OUTREACH TOOLS

Remember that all people are different and the information you are sharing will be new to most of them. Giving people time to process this new information and adapting communication approaches to meet their individual needs will go a long way in building a trusting relationship. In most case, establishing comfort and trust early in the process will help the technical work for the vapor assessment proceed more efficiently.

The DNR has a variety of resources to help from consultants and RPs with outreach and communications with affected property owners, and that can be selected to best fit the needs for a particular situation. These resources are available on-line at http://dnr.wi.gov/topic/Brownfields/Vapor.html and include:

- ***RR-958:*** introduction to vapor investigation in neighborhood and list of people to contact with questions
- ***Factsheets***: concise summaries of information about vapor intrusion to share with property owners
- ***Templates***: model access agreements and letters to request access for sampling, mitigation, and communicate the results from vapor sampling.
- ***Videos***: introduction to the concept of vapor intrusion

Vapor Intrusion 101

Share this video when needed to introduce people to the concept of vapor intrusion & how it can be fixed.

Find video at:
http://dnr.wi.gov/topic/Brownfields/VaporPublic.html

4.3 ACCESS: BEST FAITH EFFORT

The DNR expects that responsible parties will put forth a best faith effort to gain access and work cooperatively with those people whose properties may be at risk for vapor intrusion. Best faith efforts may require several different approaches and attempts to contact property owners and occupants. Each outreach effort should be documented.

As a first step, consultants and RPs are encouraged to talk directly with off-site property owners to communicate the need to gain access to their property as part of the on-going environmental investigation. These approaches will vary, and may include phone calls, in person meetings, and working with local health officials to explain the situation. In most cases, establishing comfort and trust early in the process will allow vapor investigation and mitigation to proceed more efficiently and effectively.

To demonstrate a best faith effort, the DNR expects at least two written attempts to gain access to a building. The RP should provide the DNR project manager with copies of the letters, and although not required, certified mail receipts for these letters are recommended. Templates for access letters and access agreements are available at http://dnr.wi.gov/topic/Brownfields/Vapor.html.

4.4 WHAT TO DO IF ACCESS IS DENIED?

If the RP has demonstrated a best faith effort, but an off-site property owner denies access, then the DNR project manager can send a third and final letter to the property owner and/or work with local health officials to explain the situation and encourage access. This letter will inform property owners that their denial of access after this final letter could leave them responsible for the investigation, cleanup, and/or mitigation of contamination on their property (Wis. Stat. § 292.13), and that the denial of access will be noted in the case file for the contaminated site.

The DNR project manager also evaluates if a special inspection warrant to the off-site property or issuance of an RP letter to the off-site property owner who denied access are justified. These decisions will be made on a case-by-case basis depending on the occupancy, site conditions, and potential level of risk to the occupants in the off-site property.

When vapor investigation or mitigation remains necessary, but cannot be completed because of access denial, the DNR project manager prepares a Note to the File to document the situation. This allows the responsible party to move forward with the other work needed to bring a site to closure.

However, if conditions change before closure is approved, then additional efforts to gain access to the off-site property may be needed. The more time that passes before closure, the more likely it is that there will be a change in conditions to an off-site property. The new conditions that may prompt need for additional effort to gain access include:

- change in occupancy,
- change in ownership,
- change in the level of potential risk based on new site information.

5 INVESTIGATING FOR VAPOR INTRUSION

If the vapor intrusion pathway cannot be ruled out during the screening phase, a vapor investigation is required, per Wis. Admin. Code § NR 716.11(5). The vapor investigation should proceed as soon as possible during the site investigation.

5.1 WORK PLAN

Prior to collecting vapor samples, a work plan must be prepared and submitted to the DNR within 60 days of the RP letter (Wis. Admin. Code § NR 716.07). Wis. Admin. Code § NR 716.09(2)(f) requires that the work plan include the sampling methods, parameters, quality control measures, and scope of the investigation. The purpose of a vapor investigation is to:

- Determine if subsurface concentrations pose a risk for vapor intrusion; and, if so then:
- Delineate the extent of vapor migration, and,
- Evaluate if vapor intrusion is currently impacting indoor air of occupied buildings.

Include a summary of the vapor screening in the work plan as the basis for scope of the vapor investigation.

The recommended approaches for investigating the vapor pathway are summarized in **Table 5a**.

5.2 SUB-SLAB VS. INDOOR AIR SAMPLING

Wis. Admin. Code § NR 716.11(5)(g) requires sub-slab sampling in occupied buildings when investigation of soil, groundwater or soil gas indicates potential for vapor intrusion. Wis. Admin. Code § NR 716.11(5)(h) requires indoor air sampling when it is necessary to determine the impact vapor intrusion currently has to an occupied building. The decision criteria for when to sample indoor air are summarized in **Table 5b**.

5.3 FUTURE DEVELOPMENT AT PROPERTIES

For properties that are undeveloped or planning for redevelopment, the site investigation will not only identify where remediation may be needed, but can also inform future users on how to best redevelop the property so to ensure protection from the residual contamination. Whenever possible, the vapor investigation should evaluate the vapor pathway for the proposed future use of a property. For example, if an industrial building is proposed for redevelopment as residential-commercial mixed use space, then vapors under the existing building slab should be sampled to determine if concentrations exceed *residential* vapor risk screening levels.

Undeveloped areas of a property with residual soil and/or groundwater contamination may pose a threat of vapor intrusion if buildings are constructed or expanded in the future. Because the effect a future building will have on the migration of vapors cannot be determined until the building is in place, soil gas samples alone cannot be used to rule out the vapor pathway when other vapor screening criteria are exceeded (e.g. residual TCE contamination above the NR 140 ES is present at the groundwater table). For these situations, vapor control technologies will be required for future occupied buildings, unless remediation of the vapor source is completed, and/or a vapor investigation is completed after the building is constructed and the DNR agrees that vapor control technologies are not needed (see **Section 7.5** for mitigation in new buildings).

TABLE 5a
RECOMMENDED APPROACHES FOR VAPOR INVESTIGATIONS[(a)]

1. Original contaminant discharge is located directly below or adjacent to a building.

- Collect **sub-slab** vapor samples from beneath the building foundation.
- If the building is large, step outward from the source to delineate the extent of vapor migration under the building.

2. Vapors migrating from contaminated soil to nearby buildings.

- As a first step, **soil gas** samples can be collected to help identify the pathways for sub-surface vapor migration and specific buildings at risk of vapor intrusion.
- Collect **sub-slab** vapor samples at buildings identified to be at risk for vapor intrusion from nearby soil contamination based on vapor screening criteria or results from a soil gas survey.
- If sub-slab or soil gas samples are at or over screening levels, expand the monitoring program to include additional locations/buildings as needed to define extent of sub-surface vapors that attain or are over screening levels.

3. Vapors migrating from contaminants located at the groundwater table.

- As a first step, **soil gas** samples can be collected near the water table to assess the risk of vapor migration to buildings overlying the contaminated groundwater.
- Collect **sub-slab** vapor samples at buildings that overlie contaminated groundwater and identified as at risk for vapor intrusion based on vapor screening criteria or soil gas sampling results.
- If sub-slab or soil gas samples are at or over screening levels, expand the monitoring program to include additional locations/buildings as needed to define extent of sub-surface vapors over screening levels.

4. Vapors migrating through utility line (or other preferential pathways).

- Collect **soil gas** samples along potential preferential pathways for vapor migration (e.g. utilities where CVOCs may have been directly discharged, or utilities or sand seams that intersect contaminated soil or groundwater) to determine level of impact and delineate extent of vapor migration.
- **Video logging** of sanitary or storm sewers may help to focus locations for vapor investigation in some cases.
- Collect **sub-slab** vapor samples and/or **indoor air** sampling at buildings served by the utility lines determined to be preferential pathway for vapor migration.
- Expand the monitoring program as needed to define extent of sub-surface vapors that are at or over screening levels.

5. Contaminated groundwater entering or in contact with building.

- **Indoor air** sampling or other **unique sampling** schemes may be needed depending on site conditions.
- If building has a **sump pump**, then investigate vapor intrusion pathway at sump pump:
  - Seal sump, allow time for vapor equilibration, and then collect a vapor sample from the head space of sump.
  - Collect a water sample from the sump (if water is present).
- If there are periods when soil below the building is unsaturated, collect **sub-slab** vapor samples during these drier seasonal periods.

(a) Wis. Admin. Code § NR 716.11(5)(g) requires sub-slab sampling in occupied buildings when investigation of soil, groundwater or soil gas indicates potential for vapor intrusion, and Wis. Admin. Code § NR 716.11(5)(h) requires indoor air sampling when it is necessary to determine the impact vapor intrusion currently has to an occupied building.

TABLE 5b
WHEN TO SAMPLE INDOOR AIR IN A SITE INVESTIGATION

1. Concurrent with Sub-Slab Sampling

- *Current* indoor air sampling occurs during the same monitoring event, but generally not at the same time as sub-slab sampling.
  - Typically the indoor air sample(s) are collected first, and sub-slab samples are collected when indoor air sampling is complete so as to minimize the potential for sub-slab sampling to affect the indoor air results.
  - The decision to do *concurrent* indoor air and sub-slab sampling will depend on the situation[13].
- For *residential* settings, *concurrent* sampling is recommended because:
  - Minimizes disturbance and repeated access requests to the building occupants.
  - Provides a direct answer to the occupants as to whether their indoor air is currently impacted.
  - Per Wis. Admin. Code § NR 716.11(5)(h), indoor air sampling is *expected* anytime the sub-slab vapor concentrations are at or over vapor risk screening levels in a residential setting.

2. Follow-up to Sub-Slab Sampling

- *Follow-up* indoor air sampling occurs as a separate monitoring event after initial sub-slab sampling is complete.
  - Wis. Admin. Code § NR 716.11(5)(h) requires indoor air sampling when it is necessary to determine the impact vapor intrusion currently has to an occupied building.
  - Indoor air samples are *only* collected if the results from sub-slab sampling attain or exceed a vapor risk screening level.
  - Another round of sub-slab vapor samples can be collected during the follow-up monitoring event.
- For *non-residential* settings *follow-up* indoor air sampling is recommended because:
  - Limits indoor air sampling to only those buildings (or portions of a large building) that had sub-slab vapors that were at or over vapor risk screening levels.
  - Avoids indoor air samples if other lines of evidence (e.g. tracer test) prove that vapor intrusion is not impacting the indoor air.
  - If the contaminant of concern is still in use[14], indoor air sampling can be limited to unique situations like those listed below in Item 4 below.

3. Site Conditions Prevent Sub-slab Sampling

- Contaminated groundwater intersects the building foundation.
- A utility lateral or sump penetration that is the primary pathway for vapor migration into the building.
- Vapor migration expected to occur through porous cinder block walls.
- Dirt floor crawl space instead of foundation slab.

4. Unique Situations Affecting Vapor Results

- *Heating/fuel oil discharge at a residential property*
  - Residual fuel oil contamination on the building materials may off-gas *naphthalene* into the indoor air.
  - Because of olfactory fatigue, naphthalene can exceed indoor air vapor action levels without a noticeable odor.
- *Contaminant of concern is still in use[14]*, and the indoor air is suspect as the primary source for the following:
  - Elevated vapor concentrations detected below the slab (i.e. indoor air moving into the subsurface).
  - Elevated indoor air concentrations detected in adjoining or neighboring building.

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[13] While only recommended at RP-lead sites, concurrent indoor air and sub-slab vapor sampling is *required* whenever possible at residential properties when the investigation is being completed under a *state-lead contract*.

[14] Indoor air samples are *not* recommended at non-residential facilities where the contaminants of concern are still in use because detections in indoor air may *not* be attributed to vapor intrusion, and the indoor air quality is regulated under OSHA (See Section 6.1).

5.4 VAPOR SAMPLING METHODS

Direct measurement of vapor concentrations is used to investigate the vapor intrusion pathway. The primary categories for vapor sampling include sub-slab vapor, soil gas, and indoor air/ambient air.

5.4.1 Sub-slab vapor sampling

Sub-slab vapor samples are collected from unsaturated soil directly below a building using sample probes installed through the foundation. The DNR prefers sub-slab sampling to soil gas sampling to determine the risk posed by vapor intrusion because sub-slab vapor samples are a direct measure of the environmental media in question. Sub-slab vapor samples account for the effects a building has on the vapor concentrations.

- ***Standard sub-slab sampling*** procedures are summarized in RR-986.
    - In standard, sub-slab sampling, sample probes are installed through the foundation, a Summa canister is connected to each probe, and the inherent vacuum of the canister pulls sub-slab vapor from a small radius (~ 0.5 to 2 feet) around each sample point.
    - The canister should be fitted with a flow controller that limits vapor flow to no more than 200 ml/min (a 6-liter canister will fill in approximately 30-minutes at this flow rate).
    - Standard sub-slab sampling can be used in almost any building that has a reasonable foundation and a zone of unsaturated soil below the foundation.
    - Multiple sampling events are recommended to evaluate the vapor intrusion risk at a building.
- ***High purge volume sub-slab sampling***[15] is an alternative sub-slab sampling method that can be used in large buildings[16] that have intact foundations and suitable geological conditions. This method may *not* be suitable for buildings with cracked or deteriorating foundations, or sites that have a deep and permeable vadose zone.
    - In high purge volume sampling, quality-robust sample points are installed though the foundation (see sidebar), and sub-slab vapors are pulled to each point using an energized vacuum.
    - Each sample point should be constructed at least 25 to 50 feet from outside walls, because the energized vacuum will typically have a 25 to 50 feet radius of influence.
    - High purge sampling minimizes atmospheric or seasonal influences and minimizes the potential for false positive or false negative results. Therefore, often only one high purge sampling event is needed when used in a vapor investigation.

High-Purge Sample Points

The following is *recommended* for construction of robust high-purge sample points that provide quality data:

- **Locate point away from cracks and utilities.**
- **Core a 2-inch to 6-inch hole into concrete.**
- **Remove the soil/fill to depth approximately 6-inches below foundation.**
- **Set a ½-inch to 2-inch diameter slotted PVC well screen into hole below foundation.**
- **Connect screen to riser pipe that extends approximately 1-foot above the floor. (Do NOT use PVC glue to connect screen to riser).**
- **Backfill around screen with soil or filter pack.**
- **Seal the annular space above the screen with quick grout.**
- **Allow grout to set at least 6-hours before sampling.**

[15] McAlary, T., et.al., 2010. High purge volume sampling – a new paradigm for subslab soil gas monitoring, *Ground Water Monitoring & Remediation* 30, no. 2: pp. 73 – 85.

[16] Large buildings are loosely defined as having footprint > 25,000 sf, and interior spaces are larger than the capture zone of the sample. These will primarily be industrial and commercial buildings. High purge volume sampling is not appropriate for smaller buildings where the high vacuum could result in collection of air from outside the building, or for multi-family residential buildings where building units may be smaller than the capture zone of the sample.

  - A pipe assembly connects the energized vacuum to each sample point, and should vent excess vapors to the outdoors.
  - Vapor samples are collected using a Summa canister. The intake for the Summa intake should be set in the pipe assembly at a location that ensures the sample is representative of subsurface conditions.
  - Each Summa canister should be fitted with a flow controller that limits vapor flow to no more than 200 ml/min (a 6-liter canister will fill in approximately 30-minutes at this flow rate)..
- ***Quality control measures*** are completed during sub-slab sampling to ensure the samples are representative of the subsurface vapor conditions and are not capturing ambient or indoor air. This includes installing sample points away from outside walls and cracks in the foundation, and leak testing each sample train. *Methods that allow the detection and correction of leaks prior to sample collection are preferred*.
  - ***Leak test methods for standard sub-slab sampling*** are summarized in RR-986 and include a helium shroud, shut-in testing, and water dam methods. These methods are preferred, because they can be completed prior to sampling and they do not interfere with the analysis or the target compounds. (Other leak tracer compounds are available such as pentane or isopropyl alcohol, but these tracers require laboratory analysis).
  - ***Leak test for high purge volume sampling*** often uses a smoke pen to look for leaks during the first 2 to 5 minutes after the vacuum is turned on. Leaks would be detected if smoke was visibly sucked into the sample train, port, or foundation slab. Photographs documenting that sample points are constructed away from cracks or other openings in the foundation are also recommended as a quality control procedure.
- ***Additional quality control measures*** are recommended to build confidence and increase defensibility of results in data collected from high purge volume sampling. At least one, or more, of the following quality control options are recommended for a high purge volume sample procedure::
  - ***Measure the vacuum radius of influence*** to verify the extent of the capture zone. Differential pressure/vacuum is measured at ports set into the foundation at defined distances from a sample point. Baseline readings are collected from each port before the vacuum is turned on, and differential pressure/vacuum readings are periodically recorded during sample collection. The radius of influence should be measured at ports around one sample point, at a minimum, and around additional sample points when there are known or suspected changes in foundation or subsurface conditions that could affect the size of the capture zone.
  - ***Measure the PID and/or O_2 and CO_2*** in the vapor extracted from each sample point during high purge volume sampling. Baseline readings are collected at the start, and readings are taken continuously or periodically (e.g. every 5 minutes) throughout the remainder of sampling at each point.
    - *Decrease in PID (and/or decrease in CO_2 and increase in O_2):* Less contaminated air moving into the sample point. This could be because of leakage of ambient or indoor air or because lower concentration are present below the slab at the outer edge of the capture zone. Other lines of evidence (e.g. vacuum measurements) may be needed to interpret whether change is because of leakage or changing subsurface conditions.
    - *Stable PID, O_2 and CO*: Uniform concentration of vapors within the capture zone of the sample, and leakage is unlikely.

- *Increase in PID (and/or increase in CO_2 and decrease in O_2):* Higher levels of contamination present at a distance from the sample point, and leakage is unlikely. These results can be used to zero in on hot spots of contamination below the slab.

  - ***Collect a standard sub-slab sample*** at a similar location to a high purge sample. This could be used to help validate data from high-purge sampling if the results are below screening levels in a building where higher concentrations of vapors were anticipated. A standard sub-slab sample can be collected right before high-purge sampling, or as a follow-up after the high purges volume sampling results are evaluated. If the standard sub-slab results are comparable to the high-purge results (e.g. within same order of magnitude), this correlation builds confidence in the data quality from the high-purge sampling.

5.4.2 Soil gas sampling

Soil gas samples are collected in situ from unsaturated zone soils at locations outside the footprint of a building. Soil gas samples can be a *semi-quantitative screening tool* to track vapor migration pathways, identify potential source areas, and identify buildings for future sub-slab vapor testing. They can also be a *quantitative tool* to measure vapor concentrations in utility corridors or adjacent to buildings where conditions preclude sub-slab vapor sampling (sub-slab samples are still preferred when conditions and access allow).

Special Case for PVOCs

When contaminants are PVOCs: soil gas samples collected 5-feet (laterally and vertically) from the building foundation and closest to contaminant source may be used to show aerated soil conditions are present and rule out vapor intrusion pathway for a building.

- ***Passive soil gas sampling*** is primarily used as a survey/screening tool, and investigators are referred to ESTCP[17] for additional information on passive soil gas sampling.
  - ***Devices***: In passive soil gas sampling an adsorptive sampling device is implanted directly into the ground and vapor sample is collected by diffusion in response to concentration gradients (rather than pressure gradient used in active sampling). The reported laboratory result will be mass of contaminant adsorbed to the adsorptive media.
  - ***Semi-quantitative screening*** is provided by most passive sampling methods. Semi-quantitative devices include samplers by Gore®, Beacon™, EMFLUX®, among others. These devices can be used to survey and isolate vapor migration pathways and sources. However, because these devices measure mass and not vapor concentration, *sampling results cannot be compared to vapor risk screening levels, which are concentrations.* Areas identified as having elevated soil gas concentrations in a semi-quantitative soil gas survey will often need additional quantitative testing to complete the vapor investigation.
  - ***Quantitative*** passive diffusion methods are currently under development and could be used in lieu of active soil gas sampling if the investigator can show the passive diffusion method will provide an accurate quantitative measure of the soil gas concentrations. The investigator is referred to several articles by Todd McAlary[18,19,20] for additional information on quantitative soil gas sampling.

[17] ESTCP, 2015. Development of more cost-effective methods for long-term monitoring of soil vapor intrusion to indoor air using quantitative passive diffusive-adsorptive sampling. Department of Defense Environmental Security Technology Certification Program (ESTCP) Project ER-200830. May 2015.
[18] McAlary, T., et. al. 2014a. Quantitative passive soil vapor sampling for VOCs—Part 1: theory. *Environ. Sci.: Processes Impacts* 16(3): 482–490
[19] McAlary, T., et. al. 2014b. Quantitative passive soil vapor sampling for VOCs—Part 2: laboratory experiments. E*nviron. Sci.: Processes Impacts* 16(3): 491–500.

- ***Active soil gas sampling*** approaches vary, and investigators are referred to publications by Geoprobe Systems®[21], U.S. EPA[22], and U.S EPA (2015a) for additional information on active soil gas sampling. Active soil gas sampling can provide a *quantitative* measure of vapor conditions in the subsurface, which can be compared to vapor risk screening levels. Sub-slab samples are preferred for making this risk determination, but active soil gas sampling are an acceptable alternative when conditions do not allow for sub-slab sampling.
    - ***Devices***: In active soil gas sampling, a sample probe is installed into the ground, the annular space is sealed, air is purged from the sample assembly, and soil gas sample is drawn up using a peristaltic pump, hand pump, other small vacuum, or the vacuum of a Summa canister. Samples are collected in either a Summa canister or a Tedlar® bag.
    - ***Quantitative:*** If soil gas samples will be used as a quantitative measure to evaluate the vapor intrusion pathway, Summa canisters are preferred over Tedlar® bags, and the canister should be fitted with a flow controller that provides at least a 30-minute time-weighted average concentration.

Depth for Soil Gas Samples

The sample depth will depend on site conditions, and multiple depths intervals may be needed. Factors to consider in selecting depth of soil gas samples include:

- **Set at least 3 to 4 feet below ground surface.**
- **Set within 5 feet of depth of building foundation.**
- **Set within utility corridor or other preferential pathway, if applicable.**

- ***Quality control measures*** are completed if soil gas samples will be used as a *quantitative* measure to evaluate the vapor intrusion pathway (i.e., sample concentrations will be compared to vapor risk screening levels). Quality control measures include documenting construction of a good seal between the sample probe and annulus or the soil borehole, and completing leak testing. Leak test methods for soil gas sampling are similar to sub-slab vapor sampling and include a helium shroud, shut-in testing, or other tracer testing (see RR-986).

5.4.3 Indoor air sampling

Indoor air sampling measures the concentrations of volatile compounds present in the indoor air near the sampling device during the period of sampling. Indoor air samples may be collected from a crawl space, basement, and/or other levels of a building. Sampling devices are set near the breathing zone height (if applicable), away from windows and doors, and at locations where they will not be disturbed.

- ***Pre-sampling activities*** are completed, when possible, to prepare a building for indoor air sampling:
    - Inventory and remove items from the building that may contribute VOCs to the indoor air (see **Appendix A** for common background sources). If possible, items should be removed from the building or sample space at least 24 hours prior to sampling.
    - In the summer months, windows should be closed in residential buildings, at least 24 hours prior to sampling and remain closed during sampling to minimize contributions from outdoor air. For non-commercial buildings, windows and doors can continue normal operation.

[20] McAlary, T., et. al. 2014c. Quantitative passive soil vapor sampling for VOCs—Part 3: field experiments. *Environ. Sci.: Processes Impacts* 16(3): 501–510.
[21] Geoprobe Systems®. 2006. Direct push installation of devises for active soil gas sampling & monitoring. Technical Bulletin No. MK3098. May 2006.
[22] U.S. EPA. 2001. Environmental Response Team Standard Operating Procedures, Soil Gas Sampling (SOP 2042). April 18. Currently available online at: http://www.epaosc.org/sites/2107/files/2082-r00.pdf

  - HVAC systems should continue to operate as normal, and the operating conditions should be documented and reported as part of the sampling.

- ***Active indoor air sampling*** is one option for measuring indoor air concentrations. Because vapor risk in non-residential settings is based on 8-hour exposure, active sampling set for 8-hours is usually the best approach for sampling indoor air in commercial or industrial facilities. Investigators are referred to U.S. EPA's vapor intrusion guidance (U.S. EPA 2015a) for additional information.
  - ***Summa Canister:*** The most common approach to indoor air sampling uses a Summa canister to draw air into the canister under the influence of the canister's vacuum. This sample is a direct measure of the indoor air concentration near the sampling device during the sampling period. Each canister should be fitted with a flow controller that provides either a 24-hour (residential settings) or an 8-hour (commercial/industrial settings) time-weighted average concentration.
  - ***EPA Method TO-17:*** Another option for active indoor air sampling is EPA Method TO-17. In this approach, the air is drawn through a tube containing an absorbent media using an energized pump. The average concentration in the indoor air is back-calculated based on mass absorbed to the media, the air flow rate of the energized pump, and time duration for sampling. Typically, the sample duration is between 8 to 24 hours.

    Note: Breakthrough can occur if the capacity of the adsorptive media is used up, but air continues to be pumped through the device. Breakthrough will result in a time-weighted average concentration that is biased low relative to the actual vapor concentrations. Careful planning is needed when using EPA Method TO-17 to ensure the volume of air (pumping rate x time) will not cause breakthrough.

- ***Passive indoor air sampling*** is another option to measure indoor air concentrations. Because passive samples can be collected over a longer duration than active samples, passive samples can average out the variability of indoor air. This may be useful in evaluating chronic exposure in residential settings, but may not be representative of exposure in commercial/industrial settings. Investigators are referred to documents by ESTCP (2015), NAVFAC [23], and U.S. EPA [24] for additional information on quantitative approaches to passive indoor air sampling.
  - In passive indoor air sampling, a device with sorbent media is set up to collect a sample via diffusion. The compounds able to be detected during laboratory analysis will depend on the sorbent used. The laboratory should be consulted to select the appropriate sorbent media for the contaminants of concern at a site.
  - Sorbents used within these sampler types can fall into two general categories – very strong sorbents that require solvent extraction and weaker sorbents amenable to thermal desorption. (The extraction here refers to the method the laboratory uses to desorb the contaminant mass from the sampling device for analysis). Stronger sorbents require shorter sample duration, but generally have higher analytical sensitivity.
  - Unlike passive soil gas sampling, passive indoor air sampling can provide quantitative results that can be compared to vapor action levels. The reported laboratory result will be the mass of contaminant retained by the passive sampler. For passive sampling to be a ***quantitative*** measure of indoor air vapor concentration, the time of deployment and compound-specific uptake rate for the adsorptive media must be known.

[23] NAVFAC. 2015. Passive sampling for vapor intrusion assessment. TM-NAVFAC EXWC-EV-1503. July 2015.
[24] U.S. EPA, 2014b. Engineering Issue: Passive samplers for investigation of air quality. Method description, implementation, and comparison to alternative sampling methods. EPA/600/R-14/434. December 2014.

Passive Vapor Concentration = Mass / (Uptake Rate * Time)

Concentration ($\mu g/m^3$)	Vapor concentration that can be compared to VAL for the contaminant
Mass (pg)	Mass of contaminant retained on sampler reported by lab (picograms)
Uptake Rate (mL/min)	Published look-up values that vary by sampling device and contaminant
Time (min)	Duration a passive sampler is deployed, usually days to weeks

- There are three main styles of passive sampling devices, which include tube (e.g., Drager ORSA), badge (e.g., SKC Ultra), and radial (e.g., Radiello) samplers. The style selected influences the *uptake rate*, and most passive samplers have published uptake rates for specific compounds.
- The minimum (and maximum) *time* that should be used for a passive sample can be calculated based on uptake rate, reporting limit, and expected mass. Passive samplers are often deployed for several days to several weeks.
- Because passive sampling devices can collect samples over a longer duration than active methods, passive samples can be a better indicator of chronic exposure in residential settings. This makes them useful in some situations, but may not be appropriate in all cases (e.g., evaluating acute risk for TCE in indoor air).

5.4.4 Ambient air (Background) sampling

Ambient air samples are collected from outdoors to evaluate background concentrations, and are recommended anytime indoor air or shallow soil gas samples are collected. The outdoor sample should be collected using the same procedures as the indoor sample. Sampling devices should be set upwind, near the building(s) undergoing testing, and at a location where the device is secure and will not be disturbed.

5.5 SCOPING AN INVESTIGATION

5.5.1 Laboratory Methods and Reporting

The laboratory method will depend on the sampling devices used in the investigation. EPA Method TO-15 is the most common laboratory method to analyze vapor samples collected in Summa canisters. Other laboratory methods are available for different sampling devices, and these should be selected with assistance from the laboratory to fit the reporting needs for the site.

The list of analytes reported by the laboratory should be limited to the contaminants of concern when possible.

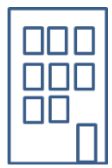
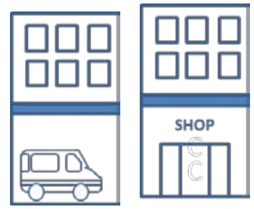
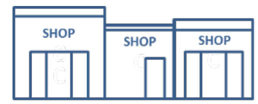
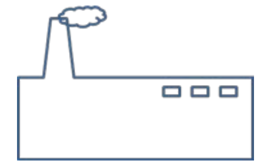
- ***For sub-slab or soil gas samples***, if the contaminants of concern are established prior to vapor sampling, the list of contaminants reported by the laboratory should be limited to the contaminants of concern for a site. If there is uncertainty in the contaminants of concern, the full list of VOCs should be reported by the laboratory for the first round of samples, but if additional samples are needed, the list of contaminants reported by the laboratory should be limited to the VOCs detected in the first round of sampling.
- ***For indoor air samples,*** the list of contaminants reported by the laboratory should be limited to the contaminants of concern for a site. There are many other sources contributing to indoor air quality, and limiting the laboratory report to the contaminants of concern for the site helps to focus the evaluation and will simplify the explanation of the results to owners and occupants of buildings. If contaminants of concern are not known, consider the option to analyze sub-slab samples first, and then select the list of analytes for indoor air samples based on what was detected in sub-slab samples.

5.5.2 Sampling Coverage and Frequency

The land use setting and the size, construction, and operations for each building will drive the scope of a vapor intrusion investigation. Basic guidelines for scoping a vapor investigation in different settings are summarized in **Table 5c**. The specific scope of an investigation will always be based on site conditions, but some general rules of thumb are as follows:

- In most cases, a vapor investigation will start and focus in building(s) or area(s) of a building where the highest vapor concentrations are expected, and will step out depending upon results of the initial sampling. However, in some cases, sampling priority should be given to nearby residential buildings that are not on the source property, but that are within an area that exceeds the vapor screening criteria.
- The sampling density (number of points per square foot of building) will typically be higher in residential settings than in non-residential buildings.
- Weather, seasonal variations, building operations, and other temporal changes affect vapor intrusion. The timing and number of sampling events should account for temporal variability. Some examples include:
  - In residential buildings, the potential for vapor intrusion can be greatest during times of decreasing outdoor temperature and in the winter months because of heating and the stack effect (see Section 8.1).
  - If a higher water table brings contaminated groundwater closer or into contact with a building's foundation, this seasonal variation can increase the potential risk for vapor intrusion.
  - On the other hand, if a lower water table exposes NAPL in the smear zone, this seasonal variation can increase the potential risk for vapor intrusion.
- Typically, more than one sampling round will be needed to demonstrate there is not a vapor risk. One exception to this is if the high-purge volume sampling method was used for a source property, often only one sampling round is needed if the data quality objectives were met.

TABLE 5c
GUIDELINES & RECOMMENDATIONS FOR SCOPING VAPOR INVESTIGATIONS

SCOPE ITEM	SETTING					
	 RESIDENTIAL	 RESIDENTIAL MULTI-FAMILY	 LARGE RESIDENTIAL (e.g. SCHOOL or DAYCARE)	 MIXED USE	 COMMERCIAL	 INDUSTRIAL
SUB-SLAB SAMPLES[a] [b]	~1/1,500 sf	~1/ 2,000 sf or 1/residence on lowest level	Fewer samples/sf than residential homes. Number of samples will depend on site conditions: – Focus samples near areas where highest vapor contamination is expected. – Depending on results, additional samples may be needed over an expanded area to delineate extent of vapor impacts. – **Barriers (e.g. footings or old exterior walls) should be factored into the selection of sample locations.** – Fewer sample points are needed for high purge volume sampling as compared to standard sub-slab vapor sampling.			
INDOOR AIR RECOMMENDED? [c]	Yes			Depends on sub-slab results (Not recommended if contaminants of concern are in use at the business.)		
SAMPLING FREQUENCY [d]	3 times		2 – 3 times		1 time (high purge volume sampling)[e] 2 – 3 times (standard sampling)	
TIME OF YEAR	At least one sample in winter and one sample in another season. (Times during decreasing temperature change may be best time to sample).				Winter preferred for at least one sample. (No restrictions for high purge volume sampling)	
ATTENUATION FACTOR DEFAULT	0.03 1 (crawl space)		0.03		0.03 (small bldgs.)[f] 0.01 (large bldgs.)[f]	0.01
ATTENUATION FACTOR SITE-SPECIFIC [g]	Not Allowed		Possible – Depending on size and condition of building			Allowed
HVAC CONSIDERATIONS	Sample with windows closed, and under normal HVAC operations.		Sample under normal HVAC and building operations, and document operating conditions. If building has distinct HVAC sectors, evaluate if sampling is needed to evaluate unique sectors.			
OTHER SPECIAL CONSIDERATIONS	If building contains a **sump** that may have contaminated water, collect water sample and/or vapor sample from sump to evaluate this as a vapor pathway.					
	Utilities can be primary entry point for vapors. Evaluate if soil gas or other unique sampling is needed to assess the utility as a vapor pathway.					
	--	**Elevators** or **vertical utilities** can move vapors to higher levels. Indoor air samples from multiple units, rooms, and/or levels may be needed.			If **contaminant of concern is still in use**, indoor vapors can migrate to the subsurface or the indoor air of neighbors.	
	--	Lower level **parking garages** may mitigate vapor intrusion into overlying occupied spaces, but this must be confirmed through testing. Sub-slab samples are still needed to complete the site investigation.			A building's **HVAC and/or foundation condition** may mitigate vapor intrusion, but sub-slab samples are still needed to complete the site investigation.	

Notes

(a) Soil gas samples can be collected along utility corridors or adjacent to buildings where conditions preclude sub-slab vapor sampling.
(b) Crawl space air sample can be used in place of sub-slab samples for buildings with crawl space. No attenuation is applied to results from crawl space samples.
(c) Background ambient air samples should be collected whenever indoor air is sampled.
(d) If fewer sample events are used to rule out the vapor pathway, a technical explanation should be provided to the DNR for approval.
(e) High purge volume sampling requires large building footprint to accommodate ~ 25-ft radius of influence for the vacuum. Sampling only once requires QA/QC documentation.
(f) Use best judgment to select small or large commercial building, and provide technical rationale for the default attenuation factor selected for a building.
(g) Site-specific attenuation factors are calculated using empirical data from the site (e.g. a radon tracer test).

6 EVALUATING VAPOR INTRUSION INVESTIGATION DATA

After vapor samples are collected, the next step is to determine whether concentrations present a risk to current or future users of a building.

6.1 BACKGROUND VAPORS

If indoor air samples were collected, it is important to remember that VOCs detected in indoor air may not have originated from the discharge of hazardous substance. There are many other contributing sources to indoor and outdoor air quality[25].

Measured concentrations of contaminants that are not the result of a hazardous substance discharge *do not* require further action under Wis. Stat. ch. 292. If concentrations detected in indoor air are determined to be primarily due to sources other than a discharge of a hazardous substance or presence of environmental pollution in the subsurface, then the vapor intrusion pathway may be ruled out. However, action may be required by other regulatory agencies or health officials.

- ***Background Outdoor Concentrations:*** VOCs can exist in outdoor air because of combustion processes, and from other industrial or commercial sources. For the purpose of a vapor intrusion assessment, these are considered to be background outdoor concentrations. Because outdoor air contributes to the quality of indoor air, the concentrations measured in the background outdoor air sample can typically be subtracted from the measured indoor air concentrations if the samples were taken on the same day and in proximity to one another.
- ***Indoor Background Sources:*** VOCs also routinely exist in indoor air because of typical household items (e.g., recently dry cleaned clothes, oil based paints, cleaners). A list of typical sources to VOCs in indoor air can be found in **Appendix A**. For the purpose of a vapor intrusion assessment, these are considered to be background sources of VOCs. Where possible, background sources should be identified and removed 24-hours prior to indoor air sampling. The potential contribution from background sources in indoor air samples should be evaluated and documented.
- ***OSHA Regulated Settings:***[26] When the contaminant of concern is also a chemical used in a manufacturing or commercial process, OSHA (Occupational Safety and Health Administration) standards or other occupational inhalation exposure guidelines apply to the occupational exposure in the indoor air as long as the entity continues to use the chemical in question. Once the OSHA standards or occupational exposure guidelines no longer apply at a building, then the indoor air must meet the vapor action levels discussed below.

6.2 VAPOR ACTION & VAPOR RISK SCREENING LEVELS

To evaluate the vapor sampling results, the data are compared either to Vapor Action Levels (VALs) for indoor air or to Vapor Risk Screening Levels (VRSLs) for subsurface samples.

[25] U.S. EPA, 2011. Background indoor air concentrations of volatile organic compounds in North American residences (1990-2005): a compilation of statistics for assessing vapor intrusion. EPA/530/R-10/001. June 2011.

[26] Indoor air is usually not sampled at OSHA regulated facilities during a vapor intrusion investigation; however, sub-slab vapor samples are still collected. In some cases, vapors from the indoor air may be able to migrate into the subsurface and affect the sub-slab vapor concentrations. If movement of vapors from indoor air into the subsurface is a concern, then indoor air sampling may be needed to make this determination.

6.2.1 VALs: Compared to Indoor Air Concentrations

VALs are based on U.S. EPA's risk values for human exposure to contaminants in indoor air[27]. Tables summarizing U.S. EPA's current risk screening levels for indoor air can be found on the U.S. EPA's website at https://www.epa.gov/risk/regional-screening-levels-rsls. U.S. EPA periodically updates these tables, and the current values should be used for making risk determination from the vapor sampling results at a site.

Wisconsin defines VALs from the U.S. EPA tables using the following criteria:

- Use the Hazard Index (HI) of 1.0 or 10^{-5} excess lifetime cancer risk[28], whichever is smaller.
- Use Residential Air exposure scenario table for a residential setting.[29]
- Use Composite Worker Air exposure scenario table for non-residential setting.[30]
- For mixed-use, use Residential Air (or provide rational for using Composite Worker Air).

6.2.2 VRSLs: Compared to Subsurface Concentrations

VRSLs are used to estimate if the concentrations detected in subsurface samples have the potential to produce indoor air concentrations over VALs. The attenuation factor tells how much the concentration in the subsurface is expected to decrease (i.e. attenuate) before reaching indoor air. This decrease will depend on sample location and building type.

$$VRSL = \frac{VAL}{Attenuation\ Factor}$$

6.2.3 Default Attenuation Factors

Wisconsin uses the default attenuation factors listed in the **Table 6a** to calculate VRSLs. The factors are grouped by land use and building size (residential/small commercial vs. industrial/large commercial):

- ***Residential and small commercial:*** The default attenuation factors in this category are taken from the U.S. EPA's vapor intrusion guidance (U.S. EPA, 2015a) and were derived from a large database of attenuation factors measured in residential buildings. *For residential dwellings, the decision to mitigate is almost always based on the VRSLs calculated from default attenuation factors.*
- ***Industrial and large commercial***: At this time, U.S. EPA has not defined default attenuation factors for industrial and large commercial buildings. However, because more dilution and mixing of indoor air are expected in these types of buildings, Wisconsin allows the default attenuation factors to decrease by a factor of 3 to 10 (depending on the sample media) for industrial and large commercial buildings.

Small vs. Large Commercial Buildings

- **There is not a hard line distinguishing small and large commercial buildings, but conceptual examples might include:**
  - ***Small commercial:* Former home that is now used only as a retail store.**
  - ***Large commercial:* Storage warehouse with wide open rooms and high ceiling.**
- **Evaluate buildings characteristics, such as:**
  - ***Building size and interior divisions***
  - ***Foundation thickness and condition***
  - ***Ceiling height***
  - ***HVAC operations or air exchange rate***
- **Apply best judgement**
- **Provide justification to DNR.**

[27] Soil inhalation pathway values are NOT an acceptable method to estimate screening values for the vapor intrusion pathway.
[28] If multiple contaminants from a vapor intrusion source are present in indoor air, the total risk (the additive risk of each of the contaminants individually) cannot exceed a HI of 1.0, or the cumulative excess lifetime cancer risk cannot exceed 10^{-5}.
[29] "Residential setting" means any dwelling designed or used for human habitation, and includes educational, childcare, and elder care settings. Wis. Admin. Code § NR 700.03(49g).
[30] "Non-residential setting" means a setting other than a residential setting, used for commercial or industrial purposes. Wis. Admin. Code § NR 700.03(39m)

TABLE 6a
DEFAULT ATTENUATION FACTORS

MEDIA	RESIDENTIAL & SMALL COMMERCIAL	INDUSTRIAL & LARGE COMMERCIAL[a]
Crawl Space	1	1
Sub-Slab Vapor	0.03	0.01
Soil Gas [b]	0.03	0.01
Deep Soil Gas/Utility[c]	0.01	0.001
Groundwater[d]	0.001	0.0001

[a] The size, foundation condition, ceiling height, interior partitioning, and HVAC of a building should be provided to support using the default industrial/large commercial attenuation factors.

[b] **Soil Gas:** These factors will apply to <u>most</u> soil gas samples. These are samples collected outside the footprint of a building, typically within 5 feet of the depth of the building foundation and at least 3 to 4 feet below ground surface.

[c] **Deep Soil Gas**: These factors apply to <u>limited</u> situations where soil gas can only be collected from deeper than 5 feet below the depth of the building's foundation or when utility is the only potential vapor migration pathway onto a property. Use of a deep soil gas attenuation factor may <u>not</u> be allowed for CVOC; however, the case for using this factor for CVOCs strengthened when geologic conditions can be shown to limit vapor migration (e.g. dense clay till between vapor source and building).

[d] **Groundwater:** Groundwater concentrations posing a potential vapor risk can be calculated from the Henry's Law constant for a contaminant, which defines partitioning into the vapor phase from groundwater at the water table:

$$C_{gw} = \frac{VAL}{H \times AF_{GW} \times 1000\ ^{L}/_{m^3}}$$

C_{gw} = Groundwater Concentration (µg/L)
VAL = Vapor Action Level (µg/m^3)
AF_{GW} = Groundwater Attenuation Factor
H = Henry's Law constant (dimensionless)

With two exceptions:
- ***Use sub-slab vapor attenuation*** factor if contaminated groundwater is located within a few feet of the depth of a building's foundation.
- ***If PCE or TCE > NR 140 ES*** at the water table, then vapor sampling is almost always needed to rule out the vapor pathway in overlying buildings.

6.2.4 Site-Specific Sub-slab Attenuation Factor (Large Buildings)

The default sub-slab attenuation factors may be overly conservative for some buildings, especially large, well-maintained facilities. For these types of buildings, if sub-slab vapor concentrations attain or are over VRSLs calculated using the default attenuation factor, then it may be appropriate to determine a site-specific attenuation factor. If a site-specific attenuation factor is found to be smaller than the default attenuation factor, then the resulting VRSLs will increase (see equation in **Section 6.2.2**) and higher subsurface vapor concentrations may be permissible at a building.

If sub-slab concentrations are over the default VRSLs, but less than the VRSLs calculated using a site-specific attenuation factor, then the currently building conditions are shown to mitigate the vapor risk and additional mitigation controls may <u>not</u> be required. However, if that is the case, the current building conditions will need to be maintained to ensure vapor intrusion remains mitigated into the future (see **Section 9**).

Getting DNR approval is recommended prior to starting the work to measure the site-specific attenuation factor. To get approval, submit a work plan with the technical assistance review fee to the DNR.

Wisconsin allows measurement of site-specific attenuation factors for industrial and large commercial buildings, but not for residential buildings[31]. (However, there may be exceptions for larger buildings with a residential setting classification [e.g., large school] that have consistent and controlled air handling). The reason is that the indoor air concentrations can vary significantly in smaller buildings, and the air handling in residential homes is inconsistent over time. These variable conditions create too much uncertainty that a site-specific attenuation factor measured today will be achievable in the future. Closure under Wis. Admin. Code § NR 726 for sites with residual vapor contamination requires assurance that interruption of the vapor pathway can be maintained.

The preferred approach for determining the site-specific attenuation factor in large buildings is through a tracer test, because this approach relies on empirical data measured at the site. More information on using tracer tests in vapor intrusion assessments is included in **Appendix B**. Other methods, including models, for determining the site-specific attenuation factor may be acceptable for large buildings. *It is recommended that a work plan be provided to the DNR for review and approval for whatever approach is selected. The work plan should include technical justification and site specific information to support using the selected approa§*

6.2.5 VAL and VRSL Summary Table

The VALs for common contaminants are summarized in the *WI Vapor Quick Look-Up Table*, which is available at http://dnr.wi.gov/topic/Brownfields/documents/vapor/vapor-quick.pdf**.** This table is updated periodically when the U.S. EPA updates their risk screening level tables. The table also includes the VRSLs calculated using the default sub-slab attenuation factors.

This table is limited to contaminants that are commonly encountered at cleanup sites, and does *not* include all contaminants posing a vapor intrusion risk. If a contaminant is not listed in this table, refer to the U.S. EPA risk screening level tables (see link in **Section 6.2.1**) to determine if the contaminant has a VAL. If it has a VAL on the U.S. EPA tables, then follow the instructions in the *WI Vapor Quick Look-Up Table* for how to determine the VALs and calculate the VRSLs for sites in Wisconsin.

6.3 ROLE OF THE DEPARTMENT OF HEALTH SERVICES

Both the DNR and Wisconsin Department of Health Services (DHS) have responsibility for ensuring that human health is protected at contaminated sites. For vapor, the DNR is focused on determining the degree and extent of vapor migration and interrupting the vapor pathway. The DHS focuses on specific situations where a risk to human health from vapor intrusion is likely, especially for residential settings.

Typically, the DNR will initiate communication with the DHS to solicit their support for the following:

- When support is needed to gain access to homes or businesses for vapor sampling/mitigation.
- To help interpret or communicate information about indoor air results.
- To address health concerns or questions related to chemical vapor exposure.
- When follow up and/or coordination is needed with local health departments.

[31] Default attenuation factors for residential buildings are based on a large and statistically significant empirical dataset of attenuation factor measured in residential homes (U.S. EPA, 2015a).

7 RESPONSE ACTIONS FOR VAPOR INTRUSION

After vapor samples results are compared to the appropriate VALs or VRSLs, the next step is to determine whether further response actions are necessary using decision criteria summarized in **Table 7a**. When sample results attain or exceed VALs or VRSLs, all lines of evidence should be evaluated to determine the likely source of the contamination and pathways for vapor migration. This may require expanding the site investigation.

When a vapor sample concentration attains or is over a VAL or a VRSL, and it is determined that vapor intrusion poses a threat to building occupants, action must be taken to address the source of the hazardous substance discharge in accordance with Wis. Stat. § 292.11(3) and Wis. Admin. Code § NR 722.09(2)(d).

Response actions for vapor intrusion are required primarily based on sub-slab vapor concentrations, but the timing for vapor mitigation can take into account other factors, such as indoor air results and land use setting. At the time of site closure, if sub-slab vapor concentrations remain at or over VRSLs, then the RP must demonstrate steps taken to remediate the source of vapors (to extent practicable), and interruption/mitigation of the vapor exposure pathway (Wis. Admin. Code § NR 726.05(8)).

7.1 IMMEDIATE ACTION TO PREVENT EXPOSURE

In some cases, immediate action pursuant to Wis. Admin. Code § NR 708 will be needed to interrupt the vapor pathway while the site undergoes additional monitoring or remediation. DHS and/or local health department should be contacted whenever indoor air concentrations are over VALs to help evaluate the risk from exposure to vapors and the potential need for immediate action. Situations, where immediate action would likely be needed include:

- Petroleum vapors from recent discharge present an explosion hazard.
- For carcinogens[32], if indoor air concentrations are over 10 times the VAL.
- For non-carcinogens[33], if indoor air concentrations are over 3 times the VAL.
- For TCE, if indoor air concentrations exceed the VAL and there is potential for a woman to be in her first trimester of pregnancy.

All lines of evidence should be evaluated to determine the likely source of the indoor air contamination. When the source is vapor intrusion, vapor mitigation (see Section 7.3) can be used to reduce levels to below VALs as part of an immediate action, but periodic indoor air testing is then needed to confirm that levels remain below VALs for occupancy. In extreme situations, the DHS and/or local health departments may declare that a situation constitutes a “human health hazard” (Wis. Stat. § 255.59), and they may need to relocate occupants of the building until indoor air concentrations decline to less than the VAL.

[32] The distinction between non-carcinogens and carcinogens is included on *WI Vapor Quick Look-up Table* and in the U.S. EPA’s risk screening level tables.

TABLE 7a
DECISION CRITERIA FOR VAPOR RESPONSE ACTIONS

1. Indoor air concentration is ≥ VAL [(b)] --> Immediate and/or Interim Action and Remediation

Indicates that there is an increased risk to human health from exposure to vapors in indoor air.

- The DNR notifies the DHS/local health of indoor air concentrations that are above VALs. DHS/local health can help evaluate the risk and the appropriate level of response.
- If indoor air concentrations are attributable to vapor intrusion[(a)], then:
  - Follow DHS/local health decision on if an immediate action is needed (see **Section 7.1**)
  - Interrupt/mitigate vapor intrusion, as soon as possible, as an interim action (see **Section 7.2**).
  - Define the extent of vapor migration from the site (see **Table 5a**).
  - Remediate to reduce the mass and concentration of the vapor source (to extent practicable) (see **Section 7.3**).

2. Sub-slab concentration is ≥ VRSLs --> Remediation and Interim Action

Indicates there is a potential for vapor intrusion to impact indoor air for current or future users of a building.

- If building is occupied, but indoor air samples were not collected initially, then it is expected that indoor air samples now be collected to determine the effect on indoor air quality for current users.[(b)]
- If indoor air concentrations are > VALs, follow steps above in Item 1.
- If indoor air concentrations are < VALs, or cannot be collected then:
  - Define the extent of migration of vapors with concentrations that are at or over VRSLs (see **Table 5a**).
  - Remediate to reduce the mass and concentration of the vapor source (to extent practicable) (see **Section 7.3**).
  - Demonstrate interruption/mitigation of the vapor intrusion pathway (see **Section 7.2**).
    - The *decision on when to implement mitigation will be determined on a case-by-case basis* depending on land use (e.g. higher priority given to residential buildings); and timing and effectiveness of the remedial action.
    - In some non-residential situations *the current building conditions may be found to interrupt the vapor pathway*. For these situations, a plan to document and maintain the current building may be sufficient.
    - In other situations, *mitigation may be postponed or delayed pending results of site remediation*. An indoor air quality monitoring program may be needed to show that indoor air remains below VALs during this time.

3. Soil gas or groundwater concentrations are ≥ VRSLs --> Remediation and Potential Interim Action

Indicates there is a potential for vapor intrusion to impact indoor air for current or future users of a building.

- Collect sub-slab and/or indoor air samples, if possible, to confirm the vapor risk at specific buildings.
- If sub-slab and/or indoor air are collected, then use decision criteria listed above in Items 1 and 2.
- If sub-slab and/or indoor air samples <u>cannot</u> be obtained, then:
  - Define the extent of conditions showing a potential vapor risk (see **Table 5a**).
  - Remediate to minimize the conditions creating a potential vapor risk (to extent practicable) (see **Section 7.3**).
  - Demonstrate interruption/mitigation of the vapor intrusion pathway (see details above under Item 2).

4. Soil gas or groundwater concentrations are < VRSLs.

Indicates that there is <u>not likely</u> to be a risk to human health from vapor intrusion.

- Possible to rule out vapor intrusion pathway after sufficient samples have been collected and preferential pathways have been evaluated for a building.
- For areas without buildings, but where other site conditions remain over vapor screening guidelines, then additional work may be needed to address the vapor pathway if the land is developed in the future (see **Section 7.5**).

5. Sub-slab concentration is < VRSLs

Indicates that there is <u>not</u> a risk to human health from vapor intrusion and vapor pathway can be ruled out after a sufficient number of samples have been collected (see Table 5b).

(a) Indoor air concentrations over VALs are not always attributable to vapor intrusion. Compare indoor air samples to subsurface vapor concentrations and other potential sources to determine if the contaminants in the indoor air are from vapor intrusion.
(b) Indoor air samples are <u>not</u> recommended at facilities where the contaminants of concern are still in use.

7.2 VAPOR MITIGATION: INTERIM ACTION

For occupied buildings where subsurface vapor conditions attain or are over VRSLs, one of the criteria for closure is mitigation of the vapor pathway (Wis. Admin. Code § NR 726.08). Vapor mitigation is generally an interim action (Wis. Admin. Code §§ NR 700.03(29) and 708.11), and the timing for when mitigation is implemented will depend on site conditions, exposure scenarios, and results from indoor air sampling. For occupied residential buildings, mitigation should occur as soon as possible after sampling identifies a potential vapor risk. Such action should be taken even if the site investigation has not been completed for the entire site.

> **IMPORTANT NOTE**
>
> **Mitigation ≠ Remediation**

To satisfy the criteria for case closure, interruption of the vapor exposure pathway must be documented per the requirements for design and implementation in Wis. Admin. Code § NR 708.11 and for interim action reports in Wis. Admin. Code. 708.15. Documentation of vapor mitigation includes:

- ***Design: Wis. Admin. Code §§ NR 708.11 and 724.11***
  Specify the design elements, their function, and area and/or building(s) requiring mitigation.
- ***Commissioning***: ***Wis. Admin. Code §§ NR 708.11, 724.15 and 724.17***
  Verify the current effectiveness of mitigation at each building.
- ***Operation, Monitoring, and Maintenance***: ***Wis. Admin. Code §§ NR 708.15, 724.13, 724.15 and 724.17***
  Prepare a plan for each system that specifies the conditions that must be maintained and monitored for continued long-term protection from vapor intrusion.

7.3 REMEDIATION OF VAPOR SOURCE

The other criterion for closure when conditions attain or are over VRSLs, is remediation to reduce the mass and concentration of the vapor source to the extent practicable (Wis. Admin. Code § NR 726.08). Remediation of the vapor source is the most effective way to eliminate the long-term risks of vapor intrusion from contaminated soils, groundwater, and/or NAPL.

Remediation is typically performed as part of the broader site clean-up. The vapor intrusion pathway should be a factor in selection of a remedy for a site, but other factors and pathways may also require consideration. For more information on the remedy selection process see Wis. Admin. Code § NR 722.

> **Remediation of volatile chemicals in the environment is covered in multitude of other guidance available through the DNR and external resources.**

7.4 PREEMPTIVE VAPOR MITIGATION – EXISTING BUILDINGS

Preemptive vapor mitigation is defined here as mitigation that is installed when vapor screening indicates a possibility of vapor intrusion but sub-slab vapor sampling will not be completed to determine if mitigation is needed for a specific building. This definition does *not* include situations where mitigation is installed to address an immediate health concern and sub-slab vapor sampling is completed at a later date; or situations where sub-slab vapor sampling is not technically feasible and an alternative plan for addressing the vapor pathway is approved by the DNR.

Wis. Admin. Code § NR 716.11(5)(g) requires sub-slab vapor sampling to investigate the vapor intrusion pathway at occupied buildings and to satisfy the criteria for case closure in Wis. Admin. Code § NR 726.05(8). *Therefore, RPs's may not select preemptive mitigation* ***in lieu of sampling*** *for existing buildings where screening indicates a potential vapor risk.*

Preemptive mitigation may be allowed in limited circumstances when an RP has made best faith efforts to complete the sampling at an off-site property, but the property owner refuses sampling but will allow mitigation. For this situation, the RP will need to do the following.

- Document their best-faith efforts to do sub-slab sampling at the off-site property (see **Section 4**).
- Allow the DNR an opportunity to talk with the off-site property owner regarding the need for sampling.
- Provide DNR written documentation from the off-site property owner acknowledging that mitigation is being installed because the site conditions indicate a vapor intrusion risk for the building, and the off-site property owner understands the property will be included in the case closure with continuing obligations.

For limited situations when preemptive mitigation is allowed, the DNR expects that the mitigation design (**Section 8**), performance verification testing (**Section 9**), and long-term OM&M plan (**Section 10**) are completed to demonstrate protection from the vapor intrusion pathway. In addition, continuing obligations (**Section 11**) will be assigned to properties with these systems at case closure.

7.5 MITIGATION IN NEW CONSTRUCTION

7.5.1 Planning and Constructing New Buildings

Vapor mitigation is often incorporated into the construction of new buildings when vapor intrusion is possible because of residual contamination, but sub-slab vapor conditions *cannot* be verified until the new building is constructed. Vapor mitigation in new construction is encouraged if the potential for vapor intrusion cannot be eliminated. Potential ways to eliminate the potential for vapor intrusion include:

- Remediate the contamination to reduce the mass and concentration of the vapor source.
- Construct building at location that meets the vapor screening criteria.

If the vapor intrusion pathway cannot be eliminated, then including features to mitigate vapor intrusion in the building design is encouraged because mitigation is often cheaper and more effective when installed at the time of new construction. American National Standards Institute (ANSI)/American Association of Radon Scientists and Technologists (AARST) has two mitigation standards that can help in the design of mitigation in new construction. These include:

- ANSI/AARST Standard CC-1000-2017, Soil Gas Control Systems in New Construction Of Buildings
- ANSI/AARST Standard CCAH-2012, Reducing Radon in New Construction of 1 & 2 Family Dwellings and Townhouses.

7.5.2 Post-Construction Sub-slab Vapor Sampling

Once a building is in place, the sub-slab vapor conditions can be verified. It is strongly recommended that sub-slab samples be collected after the building is constructed, but before a vapor mitigation system is activated. If necessary, sub-slab sample ports can be included in the design and construction of the building to minimize disturbance to the foundation or sub-grade materials after construction.

It is recommended that the first round of samples be collected at least one month after construction is complete, and that one to two additional sampling events be completed to evaluate seasonal effects in accordance with **Section 5** of this guidance.

Collecting sub-slab vapor samples *after* a new building is constructed is a simple step that may eliminate need for performance verification, long-term OM&M, and continuing obligations for vapor mitigation.

The results from the post-construction sub-slab sampling will inform the DNR whether vapor mitigation is *required* or *voluntary* based on decision criteria in **Table 7a.**

- ***Mitigation Required:***
  If post-construction sub-slab samples ≥ VRSLs or post-construction samples are not collected then performance verification testing (**Section 9**), long-term OM&M plan (**Section 10),** and continuing obligations (**Section 11**) for vapor mitigation can be required by DNR to verify effectiveness and ensure long-term protection from vapor intrusion. Many times this will mean that a passive mitigation system will need to be made active in order to meet the performance criteria (see **Section 8.3.4**).
- ***Mitigation Voluntary:***
  If post-construction sub-slab samples are < VRSLs and sufficient samples are collected to confirm that there is not a potential for vapor intrusion in the building, then the mitigating features can remain in place voluntarily, but there will be *no requirements* from the DNR for performance verification, long-term OM&M, or continuing obligations for the vapor mitigation system.

If post-construction sub-slab samples are not collected, then the RP must demonstrate that mitigation is effective for the current building occupants and that the effectiveness can be maintained for the building's occupants into the future.

8 MITIGATION DESIGN

Vapor mitigation describes engineered systems that interrupt the vapor pathway. Design of vapor mitigation systems is required per Wis. Admin. Code §§ 708 and 724. For mitigation to be effective the system must control the pathways for how subsurface vapors get into indoor air.

8.1 HOW SOIL GAS GETS INDOORS

A good mitigation design requires a basic understanding of how subsurface vapors can enter a building. The American Society of Heating, Refrigeration, and Air-Conditioning Engineering's (ASHRAE) guidance titled, *Indoor air quality guide: best practices for design, construction, and commissioning* [33] and the book titled, *Indoor Air Quality*[34] are good references on these basic principles.

Below ground, soil gas moves primarily by diffusion. Near the surface, pressure and temperature gradients (advective forces) have a stronger influence. In most situations, vapor intrusion is driven by the advection of soil gas into a building.

8.1.1 Advection (Pressure differential)

Pressure differentials drive advection, and advection is typically the dominate force within the zone of influence of a building. When the air pressure in the lowest level of a building is less than in the soil gas, soil gas can be pulled into the building. The pressure gradient that pulls soil gas into buildings is common and results from several scenarios, including:

- ***Stack Effect:*** When indoor air is warmer than outdoor air, indoor air will rise and may exhaust outside. The buoyancy of the warm indoor air pulls soil gas through cracks and other openings at the base of the building. The stack effect is often strongest during the heating season and times of decreasing temperature.
- ***Wind and Barometric Pressure***: High winds and changing barometric pressure strengthen pressure gradients, which can increase the amount of soil gas pulled indoors by the stack effect.
- ***Appliance Use***: Appliances that exhaust outside (e.g. kitchen or bathroom fans, fireplaces, central gas furnace, etc.) create negative pressure gradients, which can pull outdoor air and soil gas indoors.

These processes that create negative pressure gradients are *episodic*; and therefore, vapor intrusion can also be episodic.

8.1.2 Diffusion (Concentration differential)

Although advection can be the dominant force behind vapor intrusion, diffusion can still be a factor. Concentration differentials drive diffusion. In cases where soil gas concentrations are extremely high and/or the building foundation is thin and porous, or non-existent (dirt floor), diffusion may contribute significantly to vapor intrusion.

8.1.3 Discrete Entry Points

Transport of soil gas into a building may be focused at discrete entry points, which include, but are not limited to sumps, elevators, or utilities penetrations. These can be the primary pathway for contaminant mass flux in some buildings; however, discrete entry points may not contribute to vapor intrusion in all situations.

[33] ASHRAE, 2009. *Indoor air quality guide: best practices for design, construction, and commissioning*. IBSN:978-1-933742-59-5. Atlanta, GA.
[34] Meyer, Beat. *Indoor Air Quality*. Reading: Addison-Wesley Publishing Company, Inc., 1983.

8.2 GROUNDWATER IN CONTACT WITH BUILDING

In some cases, vapor intrusion does not result from migration of vapors in soil gas, but rather occurs because groundwater contaminated with VOCs is in contact with the building foundation and vapors volatilize from the contaminated water directly into the indoor air.

To mitigate vapor intrusion for this situation, first, the contaminated water should be prevented from contacting the building foundation or drain tile. Often this will require pumping water away from the foundation. Because this water is contaminated, characterization and permits may be needed prior to discharge. Then, after the area surrounding the foundation is dewatered, additional vapor control technologies (like those described below in **Section 8.4**) may be installed if it is determined they are needed to interrupt the vapor pathway. *For these situations, remediation of the contaminated groundwater is particularly important for long-term protection from exposure to vapor intrusion.*

8.3 ATTRIBUTES UNIQUE TO CHEMICAL VAPOR INTRUSION

Many of the same techniques and principles used to prevent the entry of methane or radon gas into buildings are used to mitigate chemical vapor intrusion. These approaches used on methane and radon provide excellent starting points when the attributes unique to chemical vapor intrusion are taken into consideration.

- ***Methane Gas Comparison:*** The constituents of concern in chemical vapor intrusion are often denser than air; whereas, methane is lighter than air and can move upward easily under its own buoyant force. As a result, passive venting systems can work well for mitigating methane gas, but require more rigorous design and construction to prevent chemical vapor intrusion. Active systems (in particular active depressurization systems) are preferred for chemical vapor intrusion in many situations.
- ***Radon Gas Comparison:*** Radon gas moves into buildings through similar pathways to chemical vapor intrusion. However, once inside the building, the radon gas decays relatively quickly compared to constituents of concern for chemical vapor intrusion (in particular CVOCs, which can persist and accumulate in the indoor air). As a result, mitigation with moderate coverage of a building may achieve target levels for radon gas, but the same design and coverage may not be sufficient to meet VALs for chemical vapor intrusion. This means that design and performance verification can be more rigorous for chemical vapor intrusion than is typical for mitigation of radon gas.

8.4 TYPES OF VAPOR MITIGATION SYSTEMS

The selection and design of a vapor mitigation system will depend on the land use setting, building specifications, and whether the system is being added to an existing building or incorporated into new construction. For purposes of this guidance, vapor mitigation has been grouped into three categories:

- Active Depressurization
- Active Indoor Air Controls
- Passive Controls

The situations where each category is most likely to be effective are summarized below in **Table 8a.** *Each of these approaches will have better likelihood of being effective when cracks, sumps, or other utility penetrations to the foundation and floors are sealed from the subsurface*.

TABLE 8a
MITIGATION APPROACHES – LIKELIHOOD OF MEETING CRITERIA FOR CASE CLOSURE [(a)(b)]

LAND USE AND BUILDING TYPE	ACTIVE DEPRESSURIZATION	ACTIVE INDOOR AIR CONTROLS	PASSIVE CONTROLS[(c)]
Existing Buildings			
Residential	Yes	Rare	Rare
Residential – Lg Bldg/Mixed Use	Yes	Depends	Rare
Non-Residential	Yes	Depends	Rare
New Construction			
Residential	Yes	Depends	Depends
Residential – Lg Bldg/Mixed Use	Yes	Depends to Yes	Depends
Non-Residential	Yes	Yes	Depends to Yes

(a) Sites with vapor concentrations at or over VRSLs can be considered for case closure following performance verification and submittal of a maintenance plan for the engineered control used to interrupt or mitigate the vapor pathway (Wis. Admin. Code §§ NR 708, 725, and 726).
(b) Mitigation designs will have better likelihood of being effective when cracks, sumps, or other utility penetrations to the foundation and floors are sealed from the subsurface.
(c) It can be very difficult to demonstrate effectiveness of passive systems in mitigating vapor intrusion. Passive controls are best when used to enhance performance of an active system and as one design element in new construction.

8.4.1 Mitigation Standards and Design

Detailed information for designing and testing vapor mitigation can be found in the ANSI/AARST Standard SGM-SF-2017, *Soil Gas Mitigation Standards for Existing Homes*[35].

Other standards for mitigation are available from ANSI/AARST[36,37,38,39] that focus on radon mitigation in new construction, large buildings, and multi-family housing. These may be useful in designing a vapor mitigation system because many of the same design principles used to mitigate radon also apply to vapor.

In addition to the ANSI/AARST standards, there is a wealth of information related to vapor mitigation available from ASHREA[35,40,41], ITRC, NAVFAC[42,43], and U.S. EPA[44,45,46]. This DNR guidance captures elements from these publications and the ANSI/AARST standards, but is not a replacement to the detailed information that is contained within these external documents. Specialized expertise or additional information that goes beyond the scope of this DNR guidance will be needed in some situations. Readers are encouraged to use the referenced standards and publications when designing a vapor mitigation system.

[35] ANSI/AARST Standard SGM-SF-2017, *Soil Gas Mitigation Standards for Existing Homes*.
[36] ANSI/AARST Standard CCAH-2012, *Reducing Radon in New Construction of 1 & 2 Family Dwellings and Townhouses.*
[37] ANSI/AARST Standard RMS-MF-2014, *Radon Mitigation Standards for Multifamily Buildings*.
[38] ANSI/AARST Standard RMS-LB-2014, *Radon Mitigation Standards for Schools and Large Buildings.*
[39] ANSI/AARST Standard CC-1000-2017, *Soil Gas Control Systems in New Construction of Buildings*.
[40] ASHRAE, 2013a. ANSI/ASHRAE Standard 62.1-2013. *Ventilation for acceptable indoor air quality*.
[41] ASHRAE, 2013b. ANSI/ASHRAE Standard 62.2-2013. *Ventilation and acceptable indoor air quality in low-rise residential buildings*.
[42] NAVFAC. 2011a. *Vapor intrusion mitigation in existing buildings fact sheet*. May 2011.
[43] NAVFAC. 2011b. *Vapor intrusion mitigation in construction of new buildings fact sheet*. August 2011.
[44] U.S. EPA, 2008. Engineering Issue: *Indoor air vapor intrusion mitigation approaches*. EPA/600/R-08/115. October 2008.
[45] U.S. EPA, 1993b. *Radon reduction techniques for existing detached houses: Technical guidance for active soil depressurization systems*. EPA/625/R-93/011. October 1993.
[46] U.S. EPA, 1993a. Air/Superfund National Technical Guidance Study Series: *Options for Developing and Evaluating Mitigation Strategies for Indoor Air Impacts at CERCLA Sites*", EP-451/R-93-012. September 1993. http://www.clu-in.org/conf/tio/vapor_021203/pb94110517.pdf

This remainder of Section 8 provides basic introductory design information for common approaches to mitigation, and additional details for each approach can be found in **Appendix C.** Each mitigation approach includes introductory information on the following:

- ***How it Works:*** The basis of design.
- ***Qualified Professionals***: Suggestions on who can help with design questions.
- ***Performance Metric(s):*** Reminder that performance verification testing will be needed for each system.
- ***Design Elements:*** List of features that interrupt the vapor pathway (see Appendix C for details).

8.4.2 Active Depressurization

Active depressurization systems are often referred to as "radon systems" for their similar use in mitigating radon gas entry in buildings and are the most common and preferred approach for mitigating chemical vapor intrusion in residential buildings. Active depressurization systems mitigate vapor intrusion by creating a negative pressure gradient between the soil gas below a building and the indoor air, which prevents the advection of soil gas into the building. Their standardized design and function makes performance verification easy relative to other vapor mitigation strategies.

Special Note on Backdrafting

In some situations, active depressurization could compete with the proper venting of non-sealed combustion chamber appliances, which could cause carbon monoxide to accumulate in the indoor air (backdrafting). If this is a concern, backdraft testing is recommended prior to, and after start-up of an active depressurization system. Backdraft testing may include smoke visualization tests, carbon monoxide monitoring, and/or consultation with an HVAC contractor.

See U.S.EPA's *Radon reduction techniques for existing detached houses* (U.S. EPA, 1993b) for more information.

Mitigation design basics for sub-slab depressurization and sub-membrane depressurization systems are summarized in **Table 8b** and **Table 8c**, respectively.

TABLE 8b
SUB-SLAB DEPRESSURIZATION – MITIGATION DESIGN BASICS

HOW IT WORKS	
Active sub-slab depressurization uses energized fan(s) or blower(s) to create a negative pressure gradient between the soil gas below a building and the indoor air. This negative pressure gradient prevents advection of soil gas into the building. The process also removes a small amount of contaminant vapor mass, which can lower the potential for chemical diffusion into the building.	
QUALIFIED PROFESSIONALS	Radon mitigation contractors; Civil/geotechnical and mechanical engineers.
PERFORMANCE METRIC	Pressure Field Extension
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Vapor-Tight Foundation • Energized Fan (e.g. Radon fan or vacuum blower) • Suction Draw or Pick-up Point(s) (e.g. Suction pit or sump crock) • Conveyance/Riser Pipes • Permeable Vapor Collection Sublayer (New construction only) • *A diagnostic vacuum connectivity test is recommended to select the appropriate fan and location of suction draw points for active sub-slab depressurization.*

TABLE 8c
SUBMEMBRANE DEPRESSURIZATION BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS Active submembrane depressurization works similarly to active sub-slab depressurization, but rather than having the foundation as a barrier between the soil gas and indoor air, a vapor-tight membrane is installed as this barrier. Submembrane systems are used in situations when a sub-slab system is not feasible (e.g. crawl spaces with dirt floor).	
QUALIFIED PROFESSIONALS	Radon mitigation contractors; Civil/geotechnical and mechanical engineers.
PERFORMANCE METRIC	Barrier Seal and Vacuum Operations
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Vapor-Tight Membrane • Energized Fan (e.g. Radon fan or vacuum blower) • Submembrane Perforated Pipes • Conveyance/Riser Pipes

8.4.3 Active Indoor Air Controls

Active indoor air controls rely on a building's air handling system to mitigate vapor intrusion risk, and are therefore best suited to large buildings where air handling can be continuously monitored and automatically controlled, or when used to enhance performance of active depressurization. Because of the inherent complexity and variability, performance verification of active indoor air controls may be challenging and is expected to vary by site.

Mitigation design basics for building pressurization, HVAC optimization, parking garage ventilation, and indoor air treatment on systems are summarized in **Table 8d, Table 8e, Table 8f,** and **Table 8g**, respectively.

Special Note on HVAC

For some large buildings, the current indoor air handling system may be able to mitigate the vapor intrusion risk. Demonstrating the effectiveness of a current air handling system in vapor mitigation may require an HVAC professional and/or use of a tracer test.

See Appendix B for information on tracer tests.

TABLE 8d
BUILDING PRESSURIZATION BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS Building pressurization creates and maintains static indoor air pressure that is higher than the air pressures outside the building. In this approach, maintaining higher indoor air pressure prevents the advective flow of soil gas into the building. This is typically accomplished by forcing fresh air into the building at a rate that exceeds the rate of exfiltration. It is difficult, if not impossible, to maintain positive pressure in spaces that are not designed for positive pressure conditions, and switching to positive pressure for a building not designed for pressurization can require a significant increase in energy use. Positive pressure for mitigation is best suited for buildings already operating under positive pressure.	
QUALIFIED PROFESSIONALS	Mechanical engineers; Certified HVAC contractors; Facility's maintenance expert
PERFORMANCE METRIC	Pressure Control and System Balance Verification
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Pressure Controller • Fresh Air Intake • List of Other Building Features that are Needed to Control Pressurization

TABLE 8e
HVAC OPTIMIZATION BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS HVAC optimization is the adjustment to the building's current HVAC operating schedule to achieve VAL during occupancy. This approach is *not* allowed in residential buildings, but may be suitable for large buildings with a large volume of air space and the ability to set and control the rate of air exchange. The mechanisms by which HVAC optimization mitigates risk will vary by site, but will be some combination of increased air exchange (dilution) and/or pressure control (reduction in the advective flow of soil gas into the building). The specific HVAC settings may be based on an iterative and robust indoor air sampling verification program. This will likely be done using a tracer test or direct indoor air sampling to measure site specific attenuation factors to demonstrate mitigation is achieved during occupancy.	
QUALIFIED PROFESSIONALS	Mechanical engineers; Certified HVAC contractors; Facility's maintenance expert
PERFORMANCE METRIC	Indoor Air Sampling and/or Tracer Testing to Establish Operating Schedule
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Air Exchange • HVAC Operation Schedule and Controls • HVAC Mechanical Specifications • Barrier Conditions

TABLE 8f
PARKING GARAGE VENTILATION BASICS –- MITIGATION DESIGN BASICS

HOW IT WORKS Lower-level parking garages are a common feature in newer mixed-use and multi-family residential buildings. In typical designs[47], parking garages maintain a negative pressure relative to the overlying building and/or exchange in fresh air to the garage space. These design elements prevent automobile exhaust from accumulating to unsafe concentrations within the garage and prevent air in the garage from flowing into the occupied spaces in the overlying building. These design features can also prevent vapor intrusion into the overlying building. The mechanisms contributing to vapor mitigation may vary by site: For example: • ***Lower-level (enclosed) parking that is designed to maintain negative pressure differential between*** the garage and overlying building. This design is easiest for demonstrating effectiveness of vapor mitigation. • ***Lower-level (enclosed) parking with high air exchange rate.*** The air exchange can dilute and remove soil gas that enters the garage. However, a note of caution, the high air exchange can create suction that pulls soil gas into the garage. The source and flow of air for air exchange should be part of performance verification for vapor mitigation. • ***Open-air parking***: The connection to outdoor air created by this design disconnects the overlying occupied building space from the subsurface air. The vapor intrusion pathway can be determined incomplete for this design if other discrete entry points are addressed.	
QUALIFIED PROFESSIONALS	Mechanical engineers; Certified HVAC contractors
PERFORMANCE METRIC	Varies with Design
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Pressure Control • Air Exchange • Ventilation System Specifications • Discrete Entry Point[48] Seals (elevator shafts or utility conduits – See **Section 8.4.4**)

[47] Kratri, M and Ayari, A., 2001. Ventilation for Enclosed Parking Garages. ASHRAE Journal. February 2001.
[48] Parking garages typically have connection to overlying occupied spaces by way of elevators and utilities. Parking ventilation may not mitigate vapor intrusion risk along these pathways, and additional effort to seal these pathways may be needed to complete the design.

TABLE 8g
INDOOR AIR TREATMENT BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS	
Indoor air treatment is a special case of indoor air control because it is generally not suited as the long-term standalone approach to vapor mitigation. However, it can be useful in immediate response actions or as an enhancement to another mitigation approach when indoor air concentrations are over VALs. Indoor air treatment does not prevent vapor intrusion, but rather uses filters and/or air exchange to reduce concentrations of contaminants in the indoor air. To be effective, sufficient fresh air must be supplied continuously to the building, or the indoor air must be circulated through a filter that is designed to remove the contaminants of concern. Indoor air sampling is typically necessary to verify short-term and long-term performance of indoor air treatment. The U.S.EPA's 2009[49] document is a good resource for additional information on residential air cleaners.	
QUALIFIED PROFESSIONALS	Mechanical engineers; Certified HVAC contractors; Facility's maintenance expert
PERFORMANCE METRIC	Indoor Air Sampling
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Air Exchanger (and/or Air Filter) Specifications • Air Circulation Rate • Coverage Zone for Air Treatment

8.4.4 Passive Controls

Passive controls are generally limited to new construction when vapor intrusion is identified as a potential issue because of residual contamination. Passive controls often appear simple in the design phase, but present challenges during performance verification because it is difficult to demonstrate that they control advection and diffusion of soil gas into a building over time.

If a passive system is installed in new construction, it is recommended that the design allow for easy conversion to an active system in the event that the passive control is ineffective or if its effectiveness cannot be verified..

Special Note on New Construction

Passive controls are commonly incorporated into the design for a new building when vapor intrusion is identified as a potential issue, but cannot be verified until the building is in place.

Refer to Section 7.5 for recommendation to test the sub-slab conditions after construction.

Mitigation design basics for passive ventilation and passive barriers are summarized in **Table 8h** and **Table 8i**, respectively.

[49] U.S. EPA, 2009. Residential air cleaners, a summary of available information; EPA-402-F-09-002. May 2009.

TABLE 8h
PASSIVE VENTILATION BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS Passive ventilation is the attempt to depressurize the soil gas below without an energized fan. Passive ventilation relies on an engineered vertical stack to create suction and prevent the advection of soil gas into the building.	
QUALIFIED PROFESSIONALS	Civil/Geotechnical or Mechanical Engineers
PERFORMANCE METRIC	Negative Pressure Field or Indoor Air Sampling
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	Passive ventilation includes many of the same design elements as active depressurization in new construction; however, air flow to create negative pressure below the building comes from the engineered vertical stack rather than an energized fan. • Permeable Vapor Collection Sublayer • Engineered Vertical Stack • Roof Vents (e.g. Wind-driven turbine)

TABLE 8i
PASSIVE BARRIER BASICS – MITIGATION DESIGN BASICS

HOW IT WORKS Passive barriers include both sheet and spray-applied membranes that are designed to prevent chemical vapor intrusion. To be effective as the primary mitigation approach, the physical barrier must prevent both the advection and diffusion of chemical vapors. This means that the barriers must be resistant to degradation, puncture, holes, and tears and be sealed at the penetrations to the building envelope (prevent advection), and have low transmissivity for the constituents of concern (minimize diffusion). *Water vapor or moisture barriers used in standard construction practices are typically not designed to mitigate chemical vapor intrusion*. Because it is difficult to verify performance of passive barriers, they are not recommended as a standalone mitigation approach for buildings. Rather, passive barriers are best when used to enhance the efficiency and performance of an active mitigation approach (e.g. to minimize the contaminant mass flux at discrete entry points), or used when vapor mitigation is opted for, but not required, in a building.	
QUALIFIED PROFESSIONALS	Civil/Geotechnical Engineers
PERFORMANCE METRIC	Construction Quality Assurance Documentation and Indoor Air Sampling
DESIGN ELEMENTS *(SEE APPENDIX C FOR DETAILS)*	• Thickness and Composition • Puncture Resistance • Seams and Penetrations Seal • Gas Diffusion

8.4.5 Mitigation at Elevators

Elevators are a special case because they may be a discrete entry point for vapor intrusion, especially when the elevator pit is located near the source of contaminated vapors. Elevators can act like a syringe that draws in sub-slab vapors and carries them to overlying occupied spaces in a building.

When new construction is planned, it is recommended that elevators be located away from residual contamination. For situations where an elevator is determined to be a pathway for vapor intrusion, it is recommended that the elevator pit be sealed to prevent vapors in soil gas from migrating into the elevator shaft. Performance verification will usually include indoor air sampling near the elevator and within the elevator pit while the elevator is operating.

9 SYSTEM COMMISSIONING

While a good design is important, the commissioning phase is the most critical step for getting DNR's approval vapor mitigation because this is when the effectiveness of the mitigation system is verified. Commissioning must be completed for *each system* and the site-specific commissioning plan must meet the following objectives:

- ***Performance Verification***: Show that the vapor mitigation system meets its design criteria – Wis. Admin. Code § NR 724.11(7). This step may also include modifications to the mitigation system if changes are needed to achieve performance criteria.
- ***Baseline Conditions:*** Record site conditions corresponding to successful mitigation – Wis. Admin. Code § NR 724.15.

Commissioning provides the data needed to demonstrate that the vapor pathway has been mitigated or interrupted, which is a requirement for case closure under Wis. Admin. Code § NR 726.05(8).

Documentation of performance verification and baseline conditions are submitted in a construction documentation report (Wis. Admin. Code § NR 724.15) and/or included within the long-term operation and maintenance plan for a system.

9.1 TIMELINE

DNR expects that commissioning start immediately after installation of a mitigation system. Commissioning is done to demonstrate effectiveness of a mitigation system over changing seasonal and atmospheric conditions. The process can last from a few months to a year, depending on site conditions and if modifications to the system are needed to satisfy performance criteria. The documentation report must be provided to DNR within 60 days after commissioning is complete (Wis. Admin. Code § NR 724.15), but status updates to the DNR project manager are recommended during commissioning.

9.2 PERFORMANCE VERIFICATION

Detailed guidelines for performance verification for active depressurization, active indoor air controls, and passive controls are summarized in **Appendix D**. *Performance verification testing should occur under normal operating conditions for a building (i.e. standard HVAC settings).*

When referring to **Appendix D**, keep the following in mind:

- The guidelines are only recommendations for how to demonstrate interruption of the vapor pathway
- There is flexibility in the parameters and criteria selected to verify performance of a mitigation system.
- Site-specific performance verification plans should be prepared with a goal to demonstrate that system meets or exceeds all design criteria (Wis. Admin. Code § NR 724.15(2)). The plan should identify the design criteria, performance verification parameters, and the technical rational for using these parameters (Wis. Admin § NR 724.11(7)).

If a mitigation system is modified because it initially did not meet its performance criteria, the minimum amount of performance verification testing begins after the performance criteria are first achieved. In other words, if it takes 6 months to get a system running correctly, then the performance monitoring to evaluate if seasonal changes will impact the effectiveness of the system begins at the end of the 6 month start-up period.

9.3 BASELINE CONDITIONS

The baseline conditions of a vapor mitigation system should be recorded by the end of the commissioning phase so that the physical appearance and mechanical operations that correspond to effective vapor mitigation are accurately documented. This includes elements that will be hidden after construction (e.g., membrane, passive ventilation collection layer, conveyance pipes inside walls), and elements that will remain visible but require future maintenance and monitoring (e.g. suction draw points, manometer, fan, ventilation, foundation as a barrier).

Guidelines on which baseline conditions to document for active depressurization, active indoor air controls, and passive controls are included in **Appendix D**. Generally, this step will include the following:

- Record the physical condition, equipment specifications, and/or operating procedures for each element needed for effective mitigation.
- Photograph each design element (hidden and visible).
- Label visible design elements with "item name" and "vapor intrusion mitigation system".
- Prepare diagram/map showing location of the design elements (hidden and visible).

10 OPERATION, MONITORING, AND MAINTENANCE (OM&M)

Effective mitigation also requires operation, monitoring, and maintenance (OM&M) of the engineered controls that work together to interrupt the vapor pathway. A site-specific long-term OM&M plan must be prepared for *each property* and include the following:

A long-term OM&M plan is needed to ensure that conditions proven to mitigate vapor intrusion remain effective in the future.

- ***Baseline Conditions:*** Summary of the baseline conditions and performance monitoring results recorded during commissioning – Wis. Admin. Code § NR 724.15.
- ***Operation and Maintenance Plan***: Checklist of inspection and maintenance activities needed for the system to continue meeting performance criteria – Wis. Admin. Code § NR 724.13.
- ***Long-Term Monitoring Plan:*** Monitoring schedule to confirm the system continues to function within a tolerable range of baseline conditions – Wis. Admin. Code § NR 724.17.

10.1 TIMELINE

Long-term OM&M will be required until it can be demonstrated that the vapor intrusion pathway no longer needs to be interrupted. In most cases, this will be when the sub-slab concentrations are below VRSLs.

Depending on the source of vapor contamination, long-term OM&M could be needed for only a few years or could be in place indefinitely. For example:

- PVOCs impacts are more likely to decrease to concentrations where mitigation is no longer needed.
- CVOC impacts are persistent and vapor mitigation may be needed indefinitely.

A long-term OM&M plan for vapor mitigation should be in place shortly after commissioning so that the conditions proven to interrupt the vapor pathway can be correctly maintained. *If significant time passes between commissioning and completing long-term OM&M, the system may need to go through the commissioning steps again to verify performance.*

10.2 LONG-TERM OM&M PLANS

A user friendly long-term OM&M plan is needed to ensure that protection from the vapor exposure pathway continues into the future. The specific requirements will vary by site depending on contaminant levels, mitigation approach, and land use setting, but it important to prepare the plan with the end user in mind (often a residential homeowner), and to satisfy the legal requirements in Wis. Admin. Code § NR 724. Guidelines on the long-term OM&M activities for active depressurization, active indoor air controls, and passive controls are summarized in **Appendix E**, and an example an OM&M inspection log that for active sub-slab depressurization in a residential building is provided in **Appendix G**.

In general, the long-term OM&M plan for a vapor mitigation system should communicate the following details as concisely and clearly as possible:

- Explanation:
  - Why the vapor mitigation system is needed (include type and location of contamination).
  - How the system interrupts the vapor pathway.

- Baseline Conditions:
    - Operating parameters (e.g. flow, pressure, on/off cycling).
    - Physical appearance/condition (photographs)
    - Layout (diagram showing location of elements of system).
    - Specifications for equipment.
- Mitigation Elements:
    - Name of elements to monitor/inspect/maintain.
    - How each element contributes to the mitigation.
    - How often to monitor/inspect/maintain.
    - What to expect to see during an inspection.
    - What to do if test/inspection falls outside of expected conditions.
- Record Keeping and Communication:
    - Points of contacts for questions.
    - Inspection log to record monitoring and maintenance.
    - Notify DNR 45 days prior actions that may alter system effectiveness (e.g. building remodel or addition).
- Explanation of Decommissioning[50]:
    - Decommissioning is a process to determine if mitigation will no longer be required by the DNR.
    - Decommissioning has a cost and will likely require assistance of a qualified professional.
    - Optional: Include information that the vapor mitigation can also be prevent intrusion of radon gas, so its continued operation may be desirable.
- Criteria for Decommissioning:
    - Change in land use, building occupancy, or risk criteria.
    - Decrease in soil vapor concentrations because of remediation or natural attenuation.
    - Other site specific criteria.
- Process for Decommissioning:
    - Notify DNR of decommissioning plan at least 45 days prior to implementing the plan.
    - Provide DNR the data that supports criteria for decommissioning the mitigation system.
    - Request DNR approval to remove the vapor mitigation requirement from the property, and pay any applicable fees to DNR (Wis. Admin. Code § NR 749).

[50] The details for decommissioning will not likely be known at the time a long-term OM&M plan is prepared. Nevertheless, it is important to provide an explanation of decommissioning and the general DNR requirements because one the most common questions associated with long-term OM&M is “when can the system be turned off?”.

11 LONG-TERM STEWARDSHIP

Although vapor mitigation is considered an interim action by regulatory standards, long-term care that continues past the point of case closure is typically required to ensure protection from the residual contamination.

11.1 CASE CLOSURE

Assuming that all other criteria for closure have been met, sites with vapor concentrations at or over VRSLs can be considered for closure if source of vapors has been remediated to extent practicable, and the vapor pathway has been shown to be interrupted or mitigated (Wis. Admin. Code § NR 726.05(8)). For affected properties, one or more of the vapor continuing obligations listed below will be required as a condition of closure, and notification must be provided to owners of the affected properties prior to closure, per Wis. Admin. Code. § NR 725 (see **Section 11.3**).

If vapor mitigation is still needed to interrupt the vapor pathway at the time of closure, a maintenance plan will be needed, per Wis. Admin. Code § NR 726.11. The long-term OM&M plan described in **Section 10** can also be used as the closure maintenance plan if it meets the requirements defined in Wis. Admin. Code § NR 726.11(2). The DNR guidance RR-981 explains what is required in a closure maintenance plan for vapor mitigation. A copy of the maintenance plan must be on file with the DNR and in the possession of the building owner, occupant, or other person(s) responsible for maintaining the system.

Vapor sampling may be needed on properties after closure. The situations requiring future sampling will be site-specific, but could include: construction of a new building near residual contamination; discontinuing use of the contaminant of concern; or interest in removing the continuing obligation from the property.

11.2 CONTINUING OBLIGATIONS

Continuing obligations are maintenance requirements and/or restrictions needed to ensure that the property use remains protective when there is residual contamination. Continuing obligations can be required as a condition of approving an interim or remedial action (Wis. Stat. § 292.12(2)), and as a condition of closure. **Table 11a** summarizes the continuing obligations that can be placed on a property for vapor depending on circumstances. Refer to DNR guidance document RR-042 for more information on vapor continuing obligations.

TABLE 11a
VAPOR CONTINUING OBLIGATIONS

WIS. ADMIN. CODE § NR	SUMMARY
726.15(2)(h)	Maintain vapor mitigation where sub-slab vapor concentrations meet or exceed VRSLs.
726.15(2)(j)	Maintain vapor mitigation where there is a vapor intrusion risk due to hydrogeological conditions.
726.15(2)(i)	Maintain vapor mitigation and/or **restrict occupancy to current use** when compounds of concern are still in use at a commercial or industrial facility, and reassess vapor intrusion before change in use.*
726.15(2)(k)	**Restrict occupancy** to non-residential use, when non-residential exposure was applied at closure.**
726.15(2)(L)	Require protective measures to eliminate or control vapor intrusion risk in **future construction** of occupied building space for areas with residual impacts but no existing buildings.

* Complete the vapor investigation after the contaminant of concern is no longer used at a facility. This continuing obligation is intended for situations where the *current use of the contaminant at the facility may affect the results of the vapor investigation.* Reassessment is required even if the land use, zoning, and other business activities remain the same.

** If a building is *not currently occupied* and mitigation was therefore not installed, then the continuing obligation can also be that the building remains unoccupied until the vapor pathway is mitigated or reassessed and finds that there is no longer a vapor intrusion risk. This is only used in limited situations (e.g. property where an affected building will be demolished or renovated in the future).

11.3 POST-CLOSURE RESPONSIBILITY AND NOTIFICATION

The statutory provision in Wis. Stat. § 292.12(5) makes it each property's owners responsibility to comply with the continuing obligations imposed on the property. These means that after the DNR grants case closure and applies continuing obligations within the closure letter, a property owner becomes responsible for the OM&M of a vapor mitigation system unless there is a legally enforceable private agreement with the RP that is provided to and on file with the DNR.

Per Wis. Admin. Code § NR 725.05, if vapor continuing obligation(s) are required for properties not owned by the RP, then the owners of the affected properties must be notified by the RP of the following prior to closure.

- Property address and the continuing obligation will be included in the DNR's closure documentation, which is an on-line database, BRRTS on the Web.
- The property owner, and any future property owners, will be responsible for complying with the continuing obligations and other conditions of closure while they own the property.

Private Agreements
RP and Property Owners

Property owners and RPs can make alternate arrangements for who is responsible for the long-term OM&M of a mitigation system. A few key factors to know about these legal agreements:

- **DNR is not a party to such agreements, nor do they enforce them.**
- **A copy must be provided to the DNR and made available on the DNR's database.**
- **Such agreements usually do *not* transfer to a new owner if the property changes hands.**

Although this notification is a requirement for case closure, it is recommended that the RP inform the property owner early in the process that they will ultimately be responsible for the long-term OM&M of a mitigation system.

11.4 POST-CLOSURE INSPECTION AND AUDITS

The DNR may require annual submittal of OM&M inspection logs, and this submittal would be the responsibility of the property owner, unless another agreement was made between the RP and property owner.

Sites with continuing obligations are candidates for audits by the DNR to check for compliance with the continuing obligations (Wis. Admin. Code § NR 727.09). Recording the long-term OM&M activities in an inspection log for vapor mitigation can help to demonstrate compliance. If the DNR identifies a lack of compliance during an audit, measures to restore the site into compliance will be required; however, the required actions will vary depending on circumstances.

11.5 DECOMMISSIONING & POST-CLOSURE MODIFICATIONS

Long-term OM&M of a vapor mitigation system is required until interruption of the vapor intrusion pathway is no longer needed (Wis. Admin. Code §§ NR 724.13(1)(c) and 727). *Decommissioning can occur before or after closure and is the process to demonstrate to the DNR that mitigation controls are no longer needed at a property*. Re-assessment of the vapor pathway based on current site conditions will be needed in almost all cases to receive DNR approval for decommissioning.

The guidelines for decommissioning mitigation systems are summarized in **Appendix F**, and generally include:

- Notify DNR of decommissioning plan at least 45 days prior to implementing the plan.
- Document current vapor conditions on the property or explain why the vapor mitigation system no longer needed. This could include:

Continued operation of a mitigation system may be desirable in some cases because it can also reduce exposure to radon gas in a building.

- Sampling to show sub-slab concentrations are now below VRSLs,
- Re-evaluating risk based on change in land use for the property, or
- Re-evaluating risk based on updates to the default VRSLs.

- Request DNR approval to remove the vapor mitigation requirement from the property, and pay any applicable fees to DNR (Wis. Admin. Code § NR 749). This will be the post-closure modification review fee for sites that have been closed.

If decommissioning is completed after case closure, the continuing obligation to maintain the vapor mitigation system can be removed from the property through the Wis. Admin § NR 727 Post-Closure Modification process. If decommissioning is not completed or approved, then the long-term OM&M requirements will remain in place for the property, and the system will continue to be a candidate for potential audits from the DNR.

12 EXAMPLES

Readers are referred to **Appendix H** for series of examples that demonstrate how to apply the principles in this guidance. These examples highlight common situations encountered during vapor assessments but do *not* include all the steps in the process; and therefore, are *not* meant to be applied. All site-specific information must be evaluated during a vapor assessment.

The five examples include:

- ***Example 1:*** CVOC Contaminated Soil Beneath a Commercial Building
- ***Example 2:*** TCE Groundwater Plume with Off-site Migration onto Residential Properties
- ***Example 3:*** PCE Contamination at a Dry Cleaner Still Using PCE
- ***Example 4:*** Redevelopment of a CVOC Contaminated Property
- ***Example 5:*** Petroleum Discharge with Free-product and Off-site Migration of Groundwater

13 REFERENCES

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Appendix A
Background Vapor Sources

APPENDIX A – BACKGROUND VAPOR SOURCES

COMMON HOUSEHOLD SOURCES OF BACKGROUND INDOOR AIR CONTAMINATION LISTED BY PRODUCT
NOTE: Analysis of indoor air should be specific to the VOCs expected from soil and/or groundwater contamination. (e.g.if CVOCs are the target chemical, then items containing CVOCs should be removed from the building at least 24 hours prior to sampling.)
Fuel containers or devices using gasoline, kerosene, fuel oil and products with petroleum distillates: - paint thinner - oil-based stains and paint - aerosol or liquid insect pest products - mineral spirits - furniture polishes
Personal care products: - nail polish - nail polish remover - colognes and perfumes - rubbing alcohol - hair spray
Dry cleaned clothes, spot removers, fabric/ leather cleaners
Household Cleaners - Oven cleaners - Carpet/upholstery cleaners - Bathroom cleaner - Appliance cleaner - Citrus (orange) oil or pine oil cleaners - Furniture/floor polish
PVC cement and primer, various adhesives, contact cement, model cement
Paint stripper and adhesive (glue) removers
Degreasers and cleaning solvents, such as: - aerosol penetrating oils - brake cleaner - carburetor cleaner - commercial solvents - electronics cleaners - spray lubricants
Moth balls and moth flakes
Aerosol spray products: - paints - cosmetics - automotive products - leather treatments - pesticides
Deodorizers, air fresheners, scented trees, potpourri, and scented candles
Hobby supplies
- paints and lacquers - solvents - glues - photo darkroom chemicals

APPENDIX A – BACKGROUND VAPOR SOURCES

COMMON HOUSEHOLD SOURCES OF BACKGROUND INDOOR AIR CONTAMINATION LISTED BY CHEMICAL[1,2]	
Acetone	rubber cement, cleaning fluids, scented candles and nail polish remover
Benzene	automobile exhaust, gasoline, cigarette smoke, scented candles, scatter rugs and carpet glue
Bromomethane	soil or space fumigant
1, 3-Butadiene	automobile exhaust and residential wood combustion
2-Butanone (MEK)	automobile exhaust, printing inks, fragrance/flavoring agent in candy and perfume, paint, glue, cleaning agents and cigarette smoke
Chlorobenzene	scented candles, plastic foam insulation and paint products
Chloroethane	Refrigerant
Chloroform	generated from chlorinated water (showers)
Cyclohexane	gasoline, paint thinner, paint and varnish remover
1,4-Dichlorobenzene	moth balls, general insecticide in farming, air deodorant and toilet disinfectant
Dichlorodifluoromethane	refrigerant (CFCs) and cleaning solvent
1, 1-Dichloroethane	plastic products (food and other packaging material) and flame retardant fabrics
1,2-Dichloroethane	molded plastic objects/decorations (particularly from China), cigarette smoke, PVC and vinyl floor adhesives[3]
1, 3-Dichloropropene	fungicides
Ethylbenzene	paint, paint thinners, insecticides, wood office furniture, scented candles and gasoline
Formaldehyde	building materials (particle board), furniture, insulation and cigarette smoke
n-Heptane	gasoline, nail polishes, wood office furniture and petroleum products
n- Hexane	gasoline, rubber cement, typing correction fluid and aerosols in perfumes
Methylene chloride	hairspray, paint stripper, rug cleaners, insecticides and furniture polish
Methyl isobutyl ketone (MIBK)	paints, varnishes, dry cleaning preparations, naturally found in oranges, grapes and vinegar
Methyl *tert* butyl ether (MTBE)	gasoline (oxygenating agent)
Naphthalene	cigarette smoke, automobile exhaust, residential wood combustion, insecticides and moth balls
Styrene	cigarette smoke, automobile exhaust, fiberglass, rubber and epoxy adhesives, occurs naturally in various fruits, vegetables, nuts and meats
Tertiary butyl alcohol (TBA)	gasoline (oxygenating agent)
1,1,2,2-Tetrachloroethane	solvent, paint and rust removers, varnishes and lacquers
Tetrachloroethene (PCE)	dry cleaning, metal degreasing, adhesives and glues, insecticides, scented candles and rug cleaner
Toluene	gasoline, automobile exhaust, polishes, nail polish, synthetic fragrances, paint, scented candles, paint thinner, adhesives and cigarette smoke
1, 1, 1-Trichloroethane	spot cleaner, glues, insecticides, drain cleaners, shoe polish
Trichloroethene (TCE)	glues, adhesives, paint removers, spot removers, rug cleaning fluids, paints, metal cleaners, and automotive cleaning and degreasing products
1, 2, 4 and 1,3,5 - Trimethylbenzene	gasoline and automobile exhaust
Xylenes, total	water sealer, gasoline, automobile exhaust, markers, paint, floor polish and cigarette smoke

[1] Department of Defense (DOD). 2009. DoD Vapor Intrusion Handbook. Prepared by the Tri-Service Environmental Risk Assessment Workgroup. January 2009.

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APPENDIX A – BACKGROUND VAPOR SOURCES

Appendix B
Tracer Test

APPENDIX B - TRACER TEST

TRACER TEST TO MEASURE SITE-SPECIFIC ATTENUATION FACTORS

A tracer test can be used to measure the site-specific attenuation factor in large buildings[1]. The site-specific attenuation measured during a tracer test provides insight into the magnitude of attenuation achieved for a large building, but mat not be a precise value because of the variability in indoor air.

Tracer tests provide empirical data to show how the current building conditions and air handling attenuate the migration of vapor from the subsurface into the indoor air. In some cases, the tracer test will show that a large building has a smaller attenuation factor than the default values (i.e. higher sub-slab VRSL can be applied to the current building conditions). If this is the case, then the active indoor air controls and building features that are contributing to the smaller attenuation factor must be identified and documented in the long-term OM&M plan for the building.

The basic steps for completing a tracer test are as follows:

STEP 1: Select Tracer Gas

During a tracer test, the concentration of the tracer gas will be measured in the sub-slab vapor and the indoor air. The criteria for selecting a good tracer gas include:

- ***Select a gas that does not have sources in the indoor or outdoor air*** (i.e. can only get indoors through vapor intrusion). This is required for an accurate measurement of attenuation.
- ***Select a gas that is currently in soil gas below a building***. Tracers are often thought of as chemicals that can be added to a system. Adding a tracer gas to the subsurface is possible in a vapor tracer tests; however, the process of introducing a tracer gas will increase the complexity and the potential for error in the test, and is expected to be very costly.

Because radon gas is naturally occurring and commonly present at high concentrations in Wisconsin soils, ***radon is a good tracer for vapor intrusion*** at most sites. For more information on use the of radon gas as a tracer investigators are referred to publications by, McHugh[2], Schuver[3], and U.S. EPA[4,5] and presentations from the 2017 U.S. EPA workshop that are available at https://iavi.rti.org/WorkshopsAndConferences.cfm.

Contaminants present in the subsurface vapor, but that do not have sources in the indoor air at a facility may also be considered. One such potential tracer for CVOC sites is cis-1,2-dichloroethene (DCE). This contaminant may be present in the sub-slab vapor as a result of the reductive dechlorination of TCE in contaminated groundwater. Vapors of *cis-1,2- DCE can be a good tracer* if they are present because this contaminant does not have a VAL and does not have common sources in indoor air.

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[1] Because indoor air and air handling in residential buildings can vary greatly over time, Wisconsin almost always relies on the default attenuation factor for residential buildings and buildings of similar size and construction. The default attenuation factors for these types of buildings are from a large dataset (U.S.EPA, 2015b)

[2] McHugh, T. E., et al. 2008. Use of radon measurements for evaluation of volatile organic compound (VOC) vapor intrusion. Environmental Forensics 9: 107-114.

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[5] U.S. EPA, 2015c. Simple, efficient, rapid methods to determine the potential for vapor intrusion into the home: temporal trends, vapor intrusion forecasting, sampling strategies, and contaminant migration routes. EPA/600/R-15/070. October 2015.

APPENDIX B - TRACER TEST

STEP 2: Measure the Concentration of Tracer Gas in Sub-slab Vapor and Indoor Air

Sub-slab vapor and indoor air samples are collected concurrently at a building. The number of sample locations, timing/frequency of sampling, and method for sampling will be determined on a case-by-case basis. The following are basic criteria to consider when setting up a tracer test:

- ***Location****:* Indoor air samples should be collected at the breathing zone height from a room/location that is near the sub-slab sample points. Sub-slab samples should be collected at locations used in the vapor investigation. Not all of the sub-slab sample locations must be used in the tracer test, but priority should be given to sampling points that had the highest sub-slab concentrations for the contaminant of concern.

- ***Timing:*** The tracer test should be completed when the potential for vapor intrusion is highest in a building. This will be when the stack effect is strongest, which typically correlates with the heating season and when cooling change in temperature is expected.

- ***Frequency:*** If the tracer test is completed when vapor intrusion is expected to be most likely and the results are definitive, one sampling event may be allowed.

- ***Method:*** The sampling method used for the indoor air must be the same method used to sample sub-slab vapor. The particular method used will depend on the tracer gas selected for a site. The recommended method for sampling *radon gas in a tracer test* is as follows:

    - Use of a continuous radon monitor is the recommended because these devices have an internal pump that allows sub-slab and indoor air samples to be collected in a manner that is similar to the collection of vapors samples in a Summa Canister, and because they can accurately detect radon at a large range of concentrations (e.g. high concentrations expected in sub-slab vapor and low concentrations expected in indoor air). An added benefit is they provide real-time data in the field.

    - Sub-slab radon samples should be collected for between 30 minutes and 6 hours. The higher the concentration of radon gas, the shorter the time that is needed for an accurate measurement.

    - Indoor air radon samples should be collected for at least 8-hours (for non-residential exposure scenario). Longer durations are recommended for indoor air because low radon concentrations are expected, and longer durations are needed for an accurate measurement.

APPENDIX B - TRACER TEST

STEP 3: Calculate the Site-Specific Attenuation Factor

The site-specific attenuation factor can be calculated for each indoor and sub-slab vapor concentration, but in some cases, it may be appropriate to use one indoor air concentration and an average of the sub-slab vapor concentrations detected during the tracer test. Work with the DNR project manager to determine which approach is appropriate for the site conditions and building configuration.

$$Attenuation\ Factor_{Site\ Specific} = \frac{Tracer\ Concentration_{\ indoor\ air}}{Tracer\ Concentration_{\ sub-slab\ vapor}}$$

STEP 4: Calculate Site-Specific VRSL and Evaluate Risk

After the site-specific attenuation factor is calculated, the next step is to calculate the VRSLs that apply to the site, using the VALs from the U.S. EPA's risk tables. This is the same method that is used to calculate the VRSL using the default attenuation factors, and instruction for how to determine VALs from the U.S. EPA's risk tables are included in the *WI Vapor Quick Look-Up Table*[6].

$$Contaminant\ VRSL_{Site\ Specific} = \frac{Contaminant\ VAL_{From\ U.S.EPA\ Tables}}{Attenuation\ Factor_{Site\ Specific}}$$

Data Evaluation:

- ***If sub-slab concentrations < Contaminant VRSL*** ***$_{Site\ Specific}$***, then current land use and building conditions have been shown to mitigate vapor intrusion risk.
- ***If sub-slab concentrations > Contaminant VRSL*** ***$_{Site\ Specific}$***, then additional engineered controls are needed to mitigate vapor intrusion risk.
- ***If sub-slab concentrations are close to Contaminant VRSL*** ***$_{Site\ Specific}$***, then additional work may be necessary to determine if additional engineered controls to mitigate vapor intrusion are needed.

STEP 5: Document Building Conditions

If sub-slab concentrations are over a default VRSL, but less than a VRSL$_{\text{Site Specific}}$, then the features that limit movement of sub-slab vapor into indoor air (e.g. building's use, size, air handling, and foundation condition) must be identified and documented. A long-term OM&M plan must be prepared in accordance with **Section 10** of this guidance, and a continuing obligation to maintain these conditions will be placed on the property at closure.

[6] Link to the WI Vapor Quick Look-Up Table http://dnr.wi.gov/topic/Brownfields/documents/vapor/vapor-quick.pdf.

Appendix C
Mitigation Design Guidelines

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

[1] These guidelines provide the framework for each mitigation approach; however, a site-specific design is required per Wis. Admin. Code §§ NR 708 and 724.
[2] Mitigation of the vapor pathway is generally demonstrated through performance verification and a long-term OM&M plan.

ACTIVE DEPRESSURIZATION:

– Refer to the ANSI/AARST Standard SGM-SF-2017, *Soil Gas Mitigation Standards for Existing Homes* for design information.

ACTIVE SUB-SLAB DEPRESSURIZATION DESIGN GUIDELINES

VAPOR-TIGHT FOUNDATION

A sealed barrier between the subsurface and indoor air is essential for a depressurization system to be effective and to run efficiently. A leaky barrier will require more energy to depressurize the area below the building. In sub-slab depressurization, the barrier is either the foundation floor (and in some cases the basement wall).

- ***Concrete Slab:*** Sealing or modifying the foundation may be needed to tighten the building envelope. Sealing may be needed at utility penetrations, cracks, sump crock pits or other discrete entry points. The method for sealing will depend on site conditions.
- ***Concrete Wall:*** Depending on the vapor source and building design, depressurization may be only needed below the floor, but in other situations depressurization may also be needed along one or more basement walls.
- ***Hollow Block Walls:*** If foundation is constructed of hollow block walls, supplemental depressurization may be necessary to mitigate the vapor risk. Hollow block walls can be a discrete entry point for vapors. U.S. EPA's *Options for Developing and Evaluating Mitigation Strategies for Indoor Air Impacts at CERCLA Sites* (U.S. EPA,1993a) provides additional information on block wall depressurization design.

ENERGIZED FAN

Active depressurization systems use an energized fan to move air and create a vacuum below a building. *A diagnostic vacuum connectivity test is recommended to optimize selection of the fan.*

- ***Vacuum Strength:*** In permeable subgrade soils low vacuum will move large quantities of air, and will likely achieve full pressure field extension. In tight soils, high vacuum can still result in minimal air flow. Proper design is critical in tight soils in order to achieve a full pressure field extension without inducing too strong a vacuum at any given point. In some instances, too high of vacuum in tighter soil conditions could pull and concentrate vapors below the building.
- ***Type:*** Radon fan(s) will likely be effective in smaller buildings, and blower(s) will likely be needed to achieve full pressure field extension in larger buildings.
- ***Location***: Fans or blowers are best located on the exterior, where noise is less of an issue and where vapor can vent to the outdoor air if crack develops in conveyance pipe. Radon fans are often mounted to an exterior wall, and blowers are often located on the roof of large buildings. If necessary, radon fans can also be located within a garage or attic space; as long as the space is not below a conditioned part of the building (e.g. fans cannot be placed in a tuck-under garage).
- ***Quantity:*** Multiple fans may be needed to achieve a full pressure field extension. The number of fans will depend on the size of building, subgrade permeability, and locations of footings or other barriers.

CONTINUED ON NEXT PAGE….

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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ACTIVE SUB-SLAB DEPRESSURIZATION DESIGN GUIDELINES

SUCTION DRAW OR PICK-UP POINTS

The energized fan is connected to the subsurface at suction draw or pick-up points. These can be new pits installed into the foundation or existing sumps retrofit for vapor mitigation. Their location and design should account for soil permeability, presences of footings or barriers that will prevent air flow below the slab, and other changes in elevation, age, or general condition of the foundation. *A diagnostic vacuum connectivity test is recommended to optimize design and placement of suction draw points below a foundation.*

- ***Suction pit:*** An area (e.g. 2' x 2') is cut into the foundation and subgrade is excavated anywhere from 0.5' to 2' below grade. Screened or open end of conveyance pipe is set into hole, pit is backfilled with gravel and capped (e.g. concrete patch) to form a vapor tight seal with the foundation and the conveyance pipe.
- ***Sumps:*** A sump can be used as a suction draw point, but this is not preferred. If the connecting drain tile is frequently saturated with water or the open drain tile does not cover the entire slab, depressurization through the sump may not be effective. Putting suction on the sump can also draw extra water into the drain tile and force the sump pump to run more frequently. If a sump is used as the draw point, it must be sealed so that it is vapor tight, yet still allows access to the sump pump as needed (e.g. a cover with a sealed hatch).
- ***Quantity:*** Multiple suction draw points may be needed to achieve a full pressure field extension. The number of points will depend on the size of building, subgrade permeability, and locations of footings or other barriers that may limit air flow. A diagnostic vacuum connectivity test can help with this design.

PERMEABLE VAPOR COLLECTION SUBLAYER

When active soil depressurization is applied to new construction the effectiveness and energy efficiency can be maximized by designing a permeable vapor collection layer in the subgrade. This engineered layer allows for full pressure field extension with minimal vacuum and suction drop points.

The NAVFAC's *Vapor intrusion mitigation in construction of new buildings* (NAVFAC, 2011b) and ANSI/AARST Standard CCAH-2012 are good resources for additional design information, including:

- permeable sub-base
  - granular earthen materials (e.g. sand or gravel) and/or
  - engineered product (e.g. Cupolex™, Vent mat)
- plenum box (centralized suction draw location)
  - vapor barrier (installed between permeable sub-base and foundation to improve vacuum efficiency).

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APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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ACTIVE SUB-SLAB DEPRESSURIZATION DESIGN GUIDELINES

CONVEYANCE/RISER PIPES

The soil gas removed from below the building should be safely vented to the atmosphere through conveyance pipes. Minimizing the number of fittings and bends that contribute to airflow drag will improve performance and energy efficiency of the system.

- ***Material***: PVC is commonly used because of its low cost and low airflow drag. Schedule 40 is typical, but higher strength or added protection may be needed in locations where impact is likely.
- ***Size***: Typically, 3-inch to 6-inch diameter riser pipes are needed. Size is based on head loss calculation (pipe length, material, and fittings), and the square footage requiring ventilation. NAVFAC (2011b) provides general rules of thumb: 3-inch riser can service up to 1,500 ft^2; 4-inch riser can service up to 4,000 ft^2; 6-inch riser can service up to 15,000 ft^2.
- ***Slope***: A continuous downward slope will allow rainwater or condensation that collects in the pipe to drain downward into the ground beneath the slab or membrane.
- ***Discharge Design:*** A straight open exit point on the pipe (without screens or elbows) is recommended because an open pipe minimizes head loss and minimizes the potential for ice build-up in winter. The amount of moisture in the air leaving the pipe is typically higher than any precipitation that may enter. Thus, allowing for open air flow at the outlet typically improves long-term performance.
- ***Discharge Location***: The discharge should vent to the atmosphere away from air intakes locations for a building. ANSI/AARST Standard SGM-SF-2017 provides guidelines for separation distances for both the building undergoing mitigation and any neighboring buildings, which include:
  - 10 feet above grade
  - 10 feet from mechanical air intakes
  - 1 foot above roof line
  - 2 feet above (or 10 feet lateral separation) from doors, windows, or other passive intakes.

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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ACTIVE SUBMEMBRANE DEPRESSURIZATION DESIGN GUIDELINES
VAPOR-TIGHT MEMBRANE A sealed barrier between the subsurface and indoor air is essential for a depressurization system to be effective and to run efficiently. Submembrane systems are used in situations when depressurization is needed, but a sub-slab system is not feasible (e.g. crawl spaces with dirt floor). In these cases, the membrane must be sealed and free of holes to prevent air flow between the ground and building. ▪ Membranes used for submembrane depressurization must be puncture resistant and have high tensile strength to prevent rips and tears, especially in high traffic areas. ▪ In general, thickness greater than 10-mil and use of cross-laminated materials improve these properties. ▪ The manufacturer's technical specifications should be included in the basis of design.
ENERGIZED FAN Active depressurization systems use an energized fan or move air and create a vacuum below a building. (See active sub-slab depressurization for guiding design principles.) Generally, submembrane systems will need one low-vacuum fan to create negative pressure below the membrane
SUBMEMBRANE SUCTION POINTS The energized fan is connected to the subsurface at suction draw or pick-up points. Submembrane suction points are pipes that penetrate the membrane at sealed locations and extend horizontally under the membrane: ▪ ***Material***: Typically perforated pipes are laid horizontally below the membrane. Some designs may include a granular backfill under the membrane as a bed for the pipe. ▪ ***Size***: ANSI/AARST Standard SGM-SF-2017 recommends that the horizontal perforated pipes be 10-ft–length and 4-in–diameter, but requires at a minimum they be 3-ft–length and 3-in–diameter. ▪ ***Quantity***: Multiple draw points may be needed to achieve a full pressure field extension. The number of points will depend on the size of building and locations of footings or other barriers.
CONVEYANCE/RISER PIPES The soil gas removed from below the building should be safely vented to the atmosphere through conveyance pipes. (See Active Sub-slab Depressurization for guiding design principles.)

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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ACTIVE INDOOR AIR CONTROLS

- Active indoor air controls are generally not allowed as the final mitigation strategy in residential dwellings (except for parking garages).
- Refer to ASHRAE (2009), ASHRAE (2013a), and ASHRAE (2013b) for more information on indoor ventilation, Kratri, M and Ayari, A., (2001) for information on parking garage ventilation, and U.S. EPA (2009) for information on residential indoor air cleaners.

BUILDING PRESSURIZATION DESIGN GUIDELINES
<u>PRESSURE CONTROLLER</u> Automated or monitored pressure control is necessary for a building using pressurization as the mitigation strategy. This will vary with building type and use, but can be as simple as a pressure controller (similar to a thermostat) to more complex building-wide systems with automated telemetry and alarm conditions. The means of pressure control and alarm must be included in the basis of design.
<u>FRESH AIR INTAKE</u> To protect human health, a building should be pressurized with a fresh source of air. If the source of indoor air is from below grade (e.g. utility tunnel or leakage through the slab) or is recirculated without removing contaminants, then the intake air may contain the contaminants of concern, and actually exacerbate or contribute to the vapor intrusion risk. The location and quality of the intake air used to maintain pressurization should be verified and discussed in the basis of design.
<u>BUILDING FEATURES THAT ALLOW FOR CONTROLLED PRESSURIZATION</u> It is difficult, if not impossible, to maintain positive pressure in spaces that are not designed for positive pressure conditions, and switching to positive pressure for a building not designed for pressurization can require significant increase in energy use. The ability for the building to maintain pressurization should be verified by a qualified professional, and the building features needed to maintain pressurization should be identified (e.g. overhead doors, egresses, and leak points in walls or ceiling).

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HVAC OPTIMIZATION DESIGN GUIDELINES

<u>AIR EXCHANGE:</u>

Air exchange is a ratio of the fresh air changes per hour divided by a volume of air space in a building. For example, if 600 $m^{3/}$hr of clean air is supplied to a building with volume of 1000 m^3, the air exchange is 0.6 hr^{-1}. The air exchange in a building is typically between 0.5 and 20 per hour, where the larger the number the more fresh air is introduced. *Higher rates of air exchange typically result in dilution and removal of indoor air contaminants. These effects can mitigate vapor intrusion if the air intake is from a clean air source.*

Because indoor spaces are kept at consistent temperatures and buffered from the wind, uniform and complete mixing is generally not achieved in the indoor air during this air exchange. In addition, the flux of contaminant mass into this transient indoor air environment is highly complex and variable. *Because of non-uniformity in air mixing and the complexity in contaminant mass flux into indoor air, air exchange alone may not be sufficient to achieve performance criteria.*

<u>HVAC OPERATION SCHEDULE AND CONTROLS</u>

Monitored and controlled HVAC operations are necessary for a building using HVAC optimization as the mitigation strategy. The HVAC controls, settings, and operating schedule can be specified following testing to confirm a building's HVAC settings can achieve mitigation performance criteria.

<u>HVAC MECHANICAL SPECIFICATIONS</u>

It is expected that mechanical parts will need to be replaced and repaired, or that the building may be altered while mitigation is required. Therefore, the HVAC components that are demonstrated through testing to mitigate the vapor intrusion should be documented so that a comparable system can remain after alternations or repairs.

<u>BARRIER CONDITIONS</u>

The conditions of the foundation can be an important factor in vapor mitigation when HVAC optimization is the mitigation strategy. In general, well-constructed slabs with minimal cracks and penetrations will allow less contaminant vapor mass flux into the building as compared to poorly constructed slabs with cracks and penetrations. Sealing may be needed at utility penetrations, cracks, pits or other discrete entry points to meet performance criteria. The means for sealing the foundation will depend on site conditions. The footprint and condition of the foundation at the point when HVAC optimization has been demonstrated meet performance criteria should be documented so that these conditions can be maintained during long-term OM&M.

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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PARKING GARAGES DESIGN GUIDELINES
PRESSURE CONTROL Maintaining a negative pressure differential between the garage and overlying building is the best mechanism for mitigating vapor intrusion when garage ventilation is selected as the mitigation approach. Not all parking garages include pressure control in their design; therefore, if this is the approach to vapor mitigation, the design and explanation for how a negative differential pressure is maintained between the lower-level parking garaged and overlying building must be identified and documented (e.g., physical building features, pressure monitor, pressure controllers).
AIR EXCHANGE: Many states have building codes that define the air exchange for enclosed parking garages. Typically, the requirement is near 0.75 cfm / square foot, which would typically be sufficient to dilute concentrations in garage air to safe levels. However, an important design consideration for vapor intrusion mitigation is the source of the dilution air. When high suction is created during ventilation, air may be pulled into the garage from below ground, which would actually increase the vapor intrusion pathway into the garage space. When air exchange is the basis of design for mitigation, the source of dilution or intake air must be identified to demonstrate that parking ventilation dilutes soil gas vapors and (and does not enhance vapor intrusion.
VENTILATION SYSTEM SPECIFICATIONS The specifications for the parking ventilation system (mechanical specifications, physical location, and sequence of operations) must be documented at the time mitigation is verified for a building.
DISCRETE ENTRY POINT SEALS Parking garages typically have connection to overlying occupied spaces by way of elevators and utilities. These can be discrete entry points for vapor intrusion into the overlying occupied spaces. Depending on building conditions, sealing of the utility penetration or elevator pit may be necessary. The condition of the utilities, elevator pits, or other potential discrete entry points must be documented at the time mitigation is verified for the building.

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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INDOOR AIR TREATMENT DESIGN GUIDELINES
Indoor air treatment is not allowed as the final mitigation approach for residential building, but may be used as a temporary measure to achieve VALs in indoor air. In almost all cases, indoor air will be sampled frequently to verify performance of indoor air treatment. The following are only the basic principles to consider in the design.
FILTER OR AIR EXCHANGER SPECIFICATIONS When an air filter is used, the specifications that demonstrate the filter's capacity and ability to remove the contaminants of concern from the indoor air must be included in the design. When an air exchanger is used, the air exchange rate and source of fresh air must be included in the design.
COVERAGE ZONE FOR AIR TREATMENT If only a portion of a building requires indoor air treatment, the extent of air space that must be influenced by the indoor air treatment must be documented. The air volume within treatment zone must be included in the design.
AIR CIRCULATION Filters and air exchangers rely on air circulation to bring the air to them in order to reduce the concentration of contaminants in the indoor air. The connection of the air spaces and the method or equipment used to circulate air in the building through the coverage zone must be included in the design.

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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PASSIVE CONTROLS

- When passive controls are used in new construction – refer to ANSI/AARST Standard CC-1000-2017, S*oil Gas Control Systems in New Construction of Buildings* and ANSI/AARST Standard CCAH-2012, *Reducing Radon in New Construction of 1 & 2 Family Dwellings and Townhouses*
- If the performance of passive control cannot be verified, then may need to convert to an active system .

PASSIVE VENTILATION DESIGN GUIDELINES

PERMEABLE VAPOR COLLECTION SUBLAYER

See Active Sub-slab Depressurization for design principles and references.

ENGINEERED VERTICAL STACK

A vertical stack is a conveyance pipe network that connects soil gas below a building directly to the atmosphere. In order to move the soil gas upward, suction is required. Suction can be created passively through buoyancy if the stack air is warmer than the outdoor air, and when wind moves across a properly vented stack. In essence, passive ventilation provides a bypass for soil gas that may otherwise get into indoor air because of the stack effect.

- ***Stack Location:*** The buoyancy of warm air rising is the primary force for ventilation in a passive system; therefore, the *conveyance pipes must be located within a "warm wall" or other protected heated space in a building.*
- ***Protection:*** Because riser pipes must be indoors in a passive system, any breaches in these interior conveyance pipes could provide a completed pathway for vapor intrusion. Therefore, physical protection of these pipes is critical, and leak testing should be done as part of performance verification.
- ***Material:*** See Conveyance Pipe – Active Sub-slab Depressurization.
- ***Size:*** See Conveyance Pipe – Active Sub-slab Depressurization.
- ***Discharge Point***: See Conveyance Pipe – Active Sub-slab Depressurization.
- ***Discharge Location:*** See Conveyance Pipe – Active Sub-slab Depressurization.

ROOF VENTS

The discharge of a passive system must vent above the roof line. The end of the pipe can be fitted with a wind-driven turbine. When the wind spins the turbine, a slight negative pressure can be created in the vertical stack, which has the potential to enhance the performance of the passive ventilation system.

APPENDIX C – MITIGATION DESIGN GUIDELINES [1,2]

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- If the performance of passive control cannot be verified, then may need to convert to an active system

PASSIVE BARRIERS DESIGN GUIDELINES
The following design details assume that a passive barrier is being attempted as the primary mitigation control. If a passive barrier is used to enhance performance of an active mitigation approach, then the material specifications for the barrier material are still important, but will be less stringent than the requirements listed below.
THICKNESS AND COMPOSITION Thicker membranes, or composite membranes designed for vapor mitigation, are generally more resistant to punctures and tears and minimize diffusion for the constituents of concern. In general, a thickness greater than 30-mil is recommended for passive barriers, but there is flexibility based on composition of the barrier and site contaminant levels. Higher levels of contamination will generally require thicker membranes.
PUNCTURE RESISTANCE The design must provide specifications to show the barrier material is resistant to holes, degradation, tears, or punctures. Cross-laminated or engineered composite layer barriers can improve puncture resistance. Verification that the final constructed barrier is vapor tight must be part of the construction quality assurance plan.
SEAMS AND PENETRATION SEAL Seams in the barrier material and at penetrations and walls into the building must be sealed to create a vapor tight condition between the soil gas and the building. Verification of a vapor tight seal at seams and must be part of the construction quality assurance plan.
GAS DIFFUSION The potential for the diffusion of soil gas through the membrane is of particular concern when a membrane is used as the primary mitigation strategy over areas where high concentrations of chemical vapors may accumulate in the subsurface. The design must provide specifications or testing results prove that the membrane materials have a low diffusion coefficient for the contaminant(s) of concern.

Appendix D
Commissioning Guidelines

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE DEPRESSURIZATION – COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
SUB-SLAB DEPRESSURIZATION	***Pressure Field Extension (PFE):*** • Differential negative pressure of 1Pa or 0.004 inch-H_2O(1) observed at all points. • Three monitoring events recommended over time period of not less than 6 months. • PFE evaluated, at minimum, in heating season and high water table time periods. • PFE measured with a micromanometer, or similar device, with accuracy of 0.25 Pa. • Vapor probes set in locations that demonstrate PFE for entire area requiring mitigation, with special consideration for changes in foundation or subsurface obstructions. ***Indoor Air:*** • Residential settings where indoor air exceeded VALs during investigation, required to collect concurrent with PFE measurements. • Residential situation where indoor air was below VALs during investigation, option to collect concurrent with one or more PFE measurements. • Not recommended for commercial or industrial sites where contaminants of concern are still used. • When required, indoor air is below VALs for at least two consecutive performance monitoring events.	***Fan Vacuum:*** • Measure at each fan at the same time that PFE is measured. • Vacuum measured using manometer, or similar device, with accuracy of 0.1 inch-H_2O. • Manometer should be permanently mounted on conveyance pipe on vacuum side of fan. ***Barrier Condition:*** • Document barrier conditions (age, footprint, general integrity and thickness) at time performance is verified. • Document sealing of any crack, sumps, utilities, or other discrete entry points. • Photograph items of significance. ***Parts Inspection:*** • Photograph as-built conditions corresponding to system status when performance is verified (conveyance pipes, suction draw points, vent clearance, electrical circuit, etc.). ***Air Flow:*** • Air flow is optional, but may be helpful to have as baseline for troubleshooting. • Measure at same time as vacuum measurements. • Air flow measured in conveyance pipe for each fan using a pitot tube, or similar device. • Establish a set point inside each pipe for flow measurements because air flow varies across pipe diameter. ***Backdraft Testing:*** (2)	If PFE cannot be achieved, document the vacuum and air flow in the conveyance pipe and other site conditions that corresponded to each situation of non-compliance. If PFE cannot be achieved, upgrade fan, add suction draw points, or improve the seal of the barrier. If indoor air VALs cannot be achieved after PFE criteria is met, identify and seal any discrete entry points not currently addressed by mitigation, and/or add supplemental mitigation controls (e.g. indoor air exchanger or treatment) to meet indoor air VALs.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE DEPRESSURIZATION – COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
SUBMEMBRANE DEPRESSURIZATION	***Membrane Seal:*** • Construction quality assurance for the installation of suction pipe and membrane, including documentation of the sealing of membrane at sidewalls, seams, and utility penetrations. • Smoke or other pressurized leak test method to confirm that membrane is gas tight. • Visual inspection of suction on the membrane when system is running. ***Indoor Air:*** • See Sub-slab Depressurization for criteria when to sample, or sample when another line of evidence is needed to verify performance. • When required for submembrane systems, sampling occurs at minimum in heating season and high water table time periods. • Indoor air is below VALs for at least two consecutive performance monitoring events	***Fan Vacuum:*** • Measure at each fan. • Monitor at least twice to evaluate seasonality (e.g. once during the heating season and once during high water table period.) • Vacuum measured using manometer, or similar device, with accuracy of 0.1 inch-H_2O. • Manometer should be permanently mounted on conveyance pipe on vacuum side of fan. ***Membrane Condition:*** • Document membrane conditions and specifications. • Document sealing of seams, sidewalls, and penetrations to membrane. ***Parts Inspection:*** • Photograph as-built conditions corresponding to system status when performance is verified (conveyance pipes, suction draw points, vent clearance, electrical circuit, etc.). ***Air Flow:*** • Air flow is optional, but may be helpful to have as baseline for troubleshooting. • Measure at same time as vacuum measurements. • Air flow measured in conveyance pipe for each fan using a pitot tube, or similar device. • Establish a set point inside each pipe for flow measurements because air flow varies across pipe diameter. ***Backdraft Testing:*** [(2)]	If membrane is not gas tight, seal the areas contributing to leaks and retest. If suction cannot be achieved across the full extent of the membrane after sealing, upgrade fan or add suction points. If indoor air VALs cannot be achieved after repairs and upgrades to submembrane system, add supplemental mitigation controls (e.g. indoor air exchanger or treatment) to meet indoor air VALs.

NOTES (ACTIVE DEPRESSURIZATION)

[(1)] Smaller differential pressure may be accepted for buildings with highly permeable subgrades (which result in high flow rates and low vacuum) or for other geologic conditions that limit the PFE, when documentation of subgrade conditions and justification for smaller vacuum is provided.
[(2)] Active depressurization can compete with the proper venting of combustion vented appliances. See referenced document (U.S.EPA,1993b) for additional information.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE INDOOR AIR CONTROLS -– COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
BDLG PRESSURIZATION(1)	***Indoor Air Pressurization:*** • Pressure balance testing from qualified professional to verify that positive pressure is maintained in building (or section of building) during occupancy. • Verify during different seasons (heating and cooling seasons, at a minimum). ***Make-Up Air:*** • Document location and source of "fresh air" ***Pressure Field Extension (PFE):*** • Optional when another line of evidence to verify pressurization, but should include Sampling Work Plan(2) • Scope will vary depending on circumstances, but will include at least one test during the heating season and one during cooling season. • Differential negative pressure of 1Pa or 0.004 inch-H_2O observed at all monitoring events for final system settings.(3) ***Tracer Test and/or Indoor Air:*** • Optional when another line of evidence is needed to verify effectiveness or when indoor air was over VALs during investigation phase, but should include a Sampling Work Plan(2) • Scope will vary depending on circumstances. More testing is needed as confidence in pressurization decreases (i.e. scope will look more like the performance verification for HVAC optimization). • Performance criteria = indoor air VALs achievable for each monitoring period – Direct measurements of indoor air, and/or – Indirect measurements of tracer to determine a site-specific attenuation factors.	***Pressure Controller:*** • Document how pressurization is controlled. • Provide the technical specifications for the pressure control device(s). • Provide the sequence of operations (logic for on/off conditions) for the pressure control. ***Alarm***: • Document notification/alarm if positive pressure is lost in building. • Provide technical specifications or sequence of operations for any alarm systems. ***HVAC Specifications:*** • Provide specifications for the current mechanical parts and automation for each HVAC system • Provide the building layout and service area for each HVAC system used for mitigation. ***Building Condition:*** • Itemize the features of the building envelop that contribute to maintaining positive pressure, and document current condition. • Document conditions that cannot be altered if building pressurization is to be maintained ***Barrier Condition:*** • Document barrier conditions (age, footprint, general integrity and thickness) at time performance is verified. • Document sealing of any crack, sumps, utilities, or other discrete entry points. • Photograph items of significance.	If "fresh air" supply has potential to introduce subsurface vapors into the indoor air because of intake location or other process, complete additional characterization of "fresh air" supply and reconfigure air intake location if necessary to mitigate vapor intrusion. If pressurization is questionable include PFE testing in performance monitoring program. If pressurization remains difficult to verify, develop and complete a site-specific performance verification plan that falls on spectrum of requirements for HVAC optimization (i.e. tracer test/indoor air testing). See additional contingency options under HVAC Optimization for next steps.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE INDOOR AIR CONTROLS -– COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
HVAC OPTIMIZATION	***Make-Up Air:*** • Document location and source of “fresh air” ***Tracer Test and/or Indoor Air:*** • This is the primary verification approach and should include a Sampling Work Plan(2) that incorporates the following criteria: • Number of samples/ft^2 will vary: – Coverage designed to evaluate each separate HVAC system and control zone. – Fewer locations needed for buildings with large air volume and consistent air handling. – More location for commercial or mixed-use buildings with smaller, divided spaces. • Minimum of four sampling events: – At least twice during heating season. – At least once during high water table time period. – At least once during cooling season. • Performance criteria = indoor air VALs achievable during each season for the established HVAC settings based on either: – Direct measurements of indoor air, and/or – Indirect measurements of tracer to determine a site-specific attenuation factors.	***HVAC Operations:*** • Record the <u>final system settings</u> = operating schedule for each HVAC system that corresponds to successful vapor mitigation. • Document how HVAC operating schedule is controlled (e.g. automation, training of facility manager, etc.). • Provide technical specifications for any automation device. ***HVAC Specifications:*** • Provide specifications for the current mechanical parts and automation for each HVAC system • Provide the building layout and service area for each HVAC system used for mitigation ***Barrier Condition:*** • Document barrier conditions (age, footprint, general integrity and thickness) at time performance is verified. • Document sealing of any crack, sumps, utilities, or other discrete entry points. • Photograph items of significance.	If “fresh air” supply has potential to introduce subsurface vapors into the indoor air because of intake location or other process, complete additional characterization of “fresh air” supply and reconfigure air intake location if necessary to mitigate vapor intrusion. If tracer /indoor air test do not meet performance criteria document the HVAC settings/building conditions that corresponded to each situation of non-compliance. If tracer /indoor air test do not meet performance criteria adjust HVAC settings for each season until performance criteria are achieved. (Multiple sampling events may be needed each season before <u>final system settings</u> are established). If performance criteria for indoor air / tracer test cannot be achieved through HVAC optimization alone, add supplemental mitigation controls (e.g. localized sub-slab depressurization system).
PARKING GARAGE VENTILATION	***Subsurface Vapor Samples:*** (4) ***Air Exchange:*** • Document air exchange – Ventilation rate of 0.75 cfm/ft^2 is typical – Recommend air exchange of 12 hr^{-1} with higher rates being more protective.	***System Operations:*** • Document how parking ventilation schedule is controlled (e.g. timer, pressure controller, indoor air [CO] levels, continuous etc.). • Provide technical specifications for any automation control device. • Document any notification/alarm for when operations fall outside of range.	If “dilution or intake air” supply has potential to introduce subsurface vapors because of location or other process, reconfigure air intake location or ventilation design to allow clean outdoor air to be the primary source of air during air exchange.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE INDOOR AIR CONTROLS -– COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
PARKING GARAGE VENTILATION (CONTINUED)	***Air Exchange (continued)*** • Determine source of intake air for the air exchange. – Open air garages use outdoor air for dilution and will meet performance criteria without additional monitoring (if discrete entry points have been addressed). – If intake air in enclosed garages can be documented and measure to come primarily come from outdoor air, then air exchange can meet performance criteria without additional monitoring. – If intake air in enclosed garages air can be pulled from subsurface, then may need to use other lines of evidence to verify performance (positive pressure). ***Negative Differential Pressure:*** • Use as another line of evidence when soil gas could be pulled into enclosed garage during air exchange. • Document that lowest level of occupied spaces of building are maintained under positive pressure relative to the parking garage. – Direct measurements of differential pressure between garage and occupied spaces preferred – In some cases certification from qualified professional that the engineered design will maintain pressure balance between the garage and building will be acceptable, but additional lines of evidence may be needed, depending on circumstances. ***Tracer Test/Indoor Air:*** • Sample when another line of evidence is needed to verify performance or when indoor air was over VALs during investigation phase. • Sampling Work Plan (2) • Sampling prioritized at occupied spaces directly over parking garage and near elevators. • Minimum of three sampling events, with at least two during heating season. • Performance criteria = indoor air VALs achievable – Direct measurements of indoor air, and/or – Indirect measurements of tracer to determine a site-specific attenuation factors. –	***Ventilation Specifications:*** • Provide air exchange rate of garage. • Provide the specifications for the current mechanical parts used for parking ventilation. • Provide the layout and service area for each parking ventilation system used for mitigation. • Include • Photograph as-built conditions of the final ventilation system. ***Barrier Condition:*** • Document barrier conditions (age, footprint, general integrity and thickness) at time performance is verified. • Document sealing of any crack, sumps, utilities, or other discrete entry points. • Photograph items of significance. ***Discrete Entry Point:*** • Document location of elevators, utilities, or other discrete entry points to occupied spaces that are within footprint of area requiring mitigation. • Photograph condition of seals or barriers at discrete entry points.	If air exchange cannot demonstrate outdoor air as primary source for dilution air, move to negative differential pressure evaluation. If negative differential pressure differential with overlying occupied spaces cannot be verified, move to a site-specific indoor air/tracer test monitoring program to verify mitigation. If indoor air concentrations are over VALs, re-assess discrete entry points as potential pathways, and seal points or modify ventilation system as needed to achieve VALs.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

ACTIVE INDOOR AIR CONTROLS -– COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
INDOOR AIR TREATMENT/ EXCHANGE	***Indoor Air:*** • Minimum of three sampling events, with at least two during heating season. • Indoor air is below VALs for at least three consecutive monitoring events.	***Filter or Air Exchanger Specifications:*** • Document the specifications for filter, air exchanger, or other air treatment device. • Document automation or operation controls.	Typically used as the contingency for short-term immediate action or to supplement another mitigation approach.

NOTES (ACTIVE INDOOR AIR CONTROLS)

(1) In some situations, building pressurization may be difficult to document. In those situations the performance monitoring plan can fall on the spectrum of the performance verification testing for HVAC optimization.

(2) Sampling Work Plan recommended because the scope of performance monitoring will vary based on building size, use, HVAC specifications, and characteristics of vapor source.

(3) Smaller differential pressure may be accepted for buildings with highly permeable subgrades (which result in high flow rates and low vacuum) or for other geologic conditions that limit the PFE, when documentation of subgrade conditions and justification for smaller vacuum is provided.

(4) In new construction, sub-slab sampling is recommended to confirm vapor conditions once building is in place. *If concentrations are less than VRSLs, then additional performance verification and long-term OM&M will not be required for the vapor mitigation.*

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

PASSIVE CONTROLS – COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
PASSIVE VENTILATION	***Subsurface Vapor Samples:*** (1) ***Pressure Field Extension (PFE):*** • Differential negative pressure of 1Pa or 0.004 inch-H_2O(2) observed at all points. • Three monitoring events recommended over time period of not less than 6 months. • PFE evaluated, at minimum, in heating season and high water table time periods. • PFE measured with a micromanometer, or similar device, with accuracy of 0.25 Pa. • Vapor probes set in locations that demonstrate PFE for entire area requiring mitigation, with special consideration for changes in foundation or subsurface obstructions. ***Indoor Air:*** • Recommended as another line of evidence if needed to verify performance of passive ventilation, and it should include a Sampling Work Plan (3) • Indoor air is below VALs for at least two consecutive performance monitoring events	***Vacuum:*** • Vacuum measured at each engineered vertical stack concurrent with performance monitoring. • Vacuum measured using manometer or micromanometer. ***Barrier Condition:*** • Document barrier conditions (age, footprint, general integrity and thickness) at time performance is verified. • Document sealing of any crack, sumps, utilities, or other discrete entry points. • Photograph items of significance. ***Parts Inspection:*** • Document the as-built conditions and location of the subgrade vapor collection layer, subgrade piping, and engineered vertical stack. • Test engineered vertical stack for leaks when installed on a "warm wall" on the interior of a building. • Photograph as-built conditions corresponding to system status when performance is verified (conveyance pipes, vent condition, etc.)	If PFE not initially achieved, improve the seal of the barrier or vertical stack and/or install a wind turbine fan on the roof vent. If engineered vertical stack has leak, repair stack so that air from subsurface only discharges to the outdoor air. If PFE cannot be achieved with passive controls, convert from a passive to active depressurization system through the addition of energized fan(s). If indoor air VAL cannot be achieved after PFE criteria is met, look for discrete entry points not currently addressed by mitigation, and/or add supplemental mitigation controls (e.g. indoor air exchanger or treatment) to meet indoor air VALs.

APPENDIX D – COMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria selected in site-specific commissioning plans.
[2] Site-specific commissioning plans should identify the design criteria and parameters to be used to verify performance (Wis. Admin. Code § NR 724.11(7)), and the rationale for how the plan will demonstrate the system meets or exceeds all design criteria after installation (Wis. Admin. Code § NR 724.15(2)).

PASSIVE CONTROLS – COMMISSIONING GUIDELINES			
MITIGATION APPROACH	PERFORMANCE MONITORING	BASELINE CONDITIONS	CONTINGENCY
PASSIVE BARRIERS (FULL BUILDING OR DISCRETE ENTRY POINTS)	***Subsurface Vapor Samples:*** (1) ***Barrier Seal:*** • Construction quality assurance for the installation and sealing of vapor barrier. • Smoke or other pressurized leak test method to confirm that membrane is gas tight. • Construction quality assurance that barrier remains vapor tight through construction. ***Indoor Air:*** • This is the primary line of evidence that barrier is effective and should be thought out in a Sampling Work Plan(3) that uses the following criteria: – Samples collected not sooner than 1 month after completion of building construction. – Minimum of three sampling events, with at least two events occurring during heating season. – Samples collected when HVAC operating. – Fewer locations needed for buildings with large air volume and consistent air handling. – More location for commercial or mixed-use buildings with smaller, divided spaces. • Demonstrate indoor air below VALs for at least three consecutive monitoring	***Discrete Entry Points:*** • Document the location of discrete entry points (e.g. elevators or utilities) that are specifically mitigated by barriers. ***Barrier Specifications:*** • Document the as-built conditions and location vapor barrier(s) verified to mitigate vapor intrusion. • Document the technical specifications of the vapor barrier. • Document the locations of any permanent sub-barrier vapor probes.	If barrier is not gas tight, repair barrier to extent practicable to provide a gas-tight seal (especially for mitigation of discrete entry points). If indoor air VAL criteria is not met, repair barrier to extent practicable (e.g. install an active depressurization system). If indoor air VAL criteria cannot be achieved with passive barrier, convert to an active system (e.g. install an active depressurization system).

NOTES (PASSIVE CONTROLS)

(1) In new construction, sub-slab sampling is recommended to confirm vapor conditions once building is in place. *If concentrations are less than VRSLs, then additional performance verification and long-term OM&M will not be required for the vapor mitigation.*

(2) Smaller differential pressure may be accepted for buildings with highly permeable subgrades (which result in high flow rates and low vacuum) or for other geologic conditions that limit the PFE, when documentation of subgrade conditions and justification for smaller vacuum is provided.

(3) Sampling Work Plan recommended because the scope of performance monitoring will vary based on building size, use, HVAC specifications, and characteristics of vapor source.

Appendix E
Long-Term OM&M Guidelines

APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

ACTIVE DEPRESSURIZATION – LONG-TERM OM&M			
MITIGATION APPROACH	MONITORING	INSPECTION AND MAINTENANCE	CONTINGENCY(1)
SUB-SLAB DEPRESSURIZATION	***Frequency:*** • At least once per year during heating season. • Include at least one additional monitoring event during high water conditions for sites with shallow water table. ***Vacuum:*** • Vacuum measured for each fan. • Measured at locations and devices established during commissioning (baseline conditions). Fixed devices are preferred. – Example: Vacuum measured using manometer, or similar device, with accuracy of 0.1 inch-H_2O mounted on conveyance pipe on vacuum side of fan. • Vacuum measurements are within the range of vacuum established during commissioning (baseline conditions).	***Frequency:*** • At least once per year • Recommended to be concurrent with depressurization verification. ***Inspection Checklist:*** • Motor for fan/blower is operating. • Suction draw points and sumps remain sealed. • Barrier (foundation) is in similar condition to baseline conditions (compare to photos). • Conveyance pipe vents are clear. • Conveyance pipes are not damaged, cracked, or blocked. • Vacuum probes (if in place for PFE testing) are in good condition and remain capped/sealed. ***Alarm Test:*** • Operational alarm recommended. • If system includes an alarm, test alarm to verify functionality (analogous to testing a smoke detector)	If fan motor fails, replace with a fan having similar specification to original fan. Fans have a life expectancy of approximately 15 years. Seal barrier, suction draw points, and sumps as needed to restore to baseline conditions or better. If vacuum measurements are outside of baseline range, troubleshoot to identify any leaks, high water, or vent blockage. Flow measurements may be needed to diagnose problem. Repair to restore baseline flow. In some cases a new fan may be needed because of decreased performance or change in site conditions. If vacuum cannot be restored to tolerable range of baseline conditions, complete pressure field extension testing to verify depressurization. Upgrade system as needed to achieve pressure field extension. When system upgrade is needed, *Commissioning* procedures are completed to verify performance and establish the new baseline conditions.

APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

<table>
<tr><th colspan="4">ACTIVE DEPRESSURIZATION – LONG-TERM OM&M</th></tr>
<tr><th>MITIGATION APPROACH</th><th>MONITORING</th><th>INSPECTION AND MAINTENANCE</th><th>CONTINGENCY(1)</th></tr>
<tr>
<td>SUBMEMBRANE DEPRESSURIZATION</td>
<td>Frequency:
At least once per year during heating season.
Include at least one additional monitoring event during high water conditions for sites with shallow water table.
Vacuum:
Vacuum measured for <u>each</u> fan.
Measured at locations and devices established during commissioning (baseline conditions). Fixed devices are preferred.
Example: Vacuum measured using manometer, or similar device, with accuracy of 0.1 inch-H_2O mounted on conveyance pipe on vacuum side of fan.
Vacuum measurements are within the range of vacuum established during commissioning</td>
<td>Inspection & Maintenance Frequency:
At least once per year
Recommended to be concurrent with depressurization verification.
Inspection Checklist:
Motor for fan/blower is operating.
Visual inspection of membrane for any defects and to observe if suction achieved over full extent of membrane.
Conveyance pipe vents are clear.
Conveyance pipes are not damaged, cracked, or blocked.
Alarm Test:
Operational alarm recommended.
If system includes an alarm, test alarm to verify functionality (analogous to testing a smoke detector)</td>
<td>If fan motor fails, replace with a fan having similar specification to original fan. Fans have a life expectancy of approximately 15 years.

If membrane contains rips or tears or is not sealed at seams or sidewalls, repair defect to restore to vapor tight conditions.

If vacuum measurements are outside of baseline range, troubleshoot to identify any leaks, high water, or vent blockage. Flow measurements may be needed to diagnose problem. Repair to restore baseline flow. In some cases a new fan may be needed because of decreased performance or change in site conditions.

If vacuum cannot be restored to tolerable range, replace membrane or upgrade fan. When membrane is replaced or system upgrade is needed, Commissioning procedures are recommended to verify performance and establish the new baseline conditions.</td>
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NOTES:

(1) Long-term OM&M will often be the responsibility of the property owner. However, a qualified professional may be needed to complete the contingency action in many situations.
(2) The scope of the monitoring program will vary by site based on basis of mitigation design and commissioning results.
(3) The decision to include indoor air samples in the long-term monitoring will be made on case-by-case basis depending on building size, use, HVAC specifications, characteristics of vapor source, and whether or not the mitigation approach is stand-alone option or supplement to another mitigation strategy.

APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

ACTIVE INDOOR AIR CONTROLS – LONG-TERM OM&M			
MITIGATION APPROACH	MONITORING	INSPECTION AND MAINTENANCE	CONTINGENCY(1)
BDLG PRESSURIZATION	***Pressurization Verification Frequency:*** • At least once per year during the heating season. ***Indoor Air Pressurization:*** • Pressure balance testing from qualified professional to verify that positive pressure is maintained in building (or section of building) during occupancy. • Verify that the settings and specifications for the pressure control device are within tolerable range of baseline conditions.(2) ***Indoor Air:*** *(3)*	***Maintenance Frequency:*** • As needed to maintain HVAC system. ***Maintenance Activities:*** • Repair or replace HVAC system components with items that meet the specifications established during *Commissioning*. ***Inspection Frequency:*** • At least once per year • Recommended to be concurrent with pressurization verification. ***Inspection Checklist:*** • HVAC system (mechanical parts, processes, and service area coverage) are consistent with baseline conditions. • Features critical to maintaining building pressurization have not been altered from baseline conditions. • Barrier (foundation) is in similar condition to baseline conditions (compare to photos). • Source of "fresh air" is same as baseline. ***Alarm Test:*** • If system includes an alarm, test alarm to verify functionality (analogous to testing a smoke detector).	Complete pressure balancing as needed to re-establish positive pressure conditions. If pressure control device fails or falls out of range of baseline condition, replace to restore positive pressure in building. If HVAC system, barrier, "fresh air" supply, or other site features essential to maintaining positive pressure are changed from baseline conditions, evaluate and repair as needed to restore positive pressure in building. If pressurization cannot be reestablished in the building, complete *Commissioning* procedures for building pressurization and/or HVAC optimization to verify performance and establish the new baseline conditions.

APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

<table>
<tr><th colspan="4">ACTIVE INDOOR AIR CONTROLS – LONG-TERM OM&M</th></tr>
<tr><th>MITIGATION APPROACH</th><th>MONITORING</th><th>INSPECTION AND MAINTENANCE</th><th>CONTINGENCY(1)</th></tr>
<tr><td>HVAC OPTIMIZATION</td><td>Verification testing will depend on the mechanism determined to mitigate vapor intrusion during Commissioning(2).

Indoor Air: (3)</td><td>Maintenance Frequency:
• As needed to maintain HVAC system.
Maintenance Activities:
• Repair or replace HVAC system components with items that meet the baseline design specifications established during Commissioning.

Inspection Frequency:
• At least three times per year to confirm HVAC settings:
– Twice during heating season
– Once during cooling season
• At least once per year for other inspection.
Inspection Checklist:
• Verify that the settings for each HVAC system are within tolerable range of baseline conditions.(2)
• Check for any changes to each HVAC system (mechanical parts, processes, and service area coverage) relative to the baseline conditions.
• Check the barrier (e.g. foundation) for any cracks or change in conditions from baseline.
• Confirm source of “fresh air”.</td><td>If HVAC settings fall out of range of baseline condition, restore settings to within tolerable range of baseline established for building.

Repair barrier or “fresh air” supply as needed to maintain mitigating conditions.

If the baseline HVAC settings, barrier conditions, or “fresh air” supply cannot be reestablished, complete Commissioning procedures to verify performance and establish the new baseline conditions.</td></tr>
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APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

ACTIVE INDOOR AIR CONTROLS – LONG-TERM OM&M			
MITIGATION APPROACH	MONITORING	INSPECTION AND MAINTENANCE	CONTINGENCY(1)
PARKING GARAGE VENTILATION	***Verification testing will depend on the mechanism determined to mitigate vapor intrusion during Commissioning(2). In most cases this will be air exchange rate.*** ***Frequency:*** • At least once per year during the heating season. ***Indoor Air:*** (3)	***Maintenance Frequency:*** • As needed to maintain ventilation. ***Maintenance Activities:*** • Repair or replace ventilation system components with items that meet the specifications established during *Commissioning*. ***Inspection Frequency:*** • At least once per year • Recommended to be concurrent with pressurization verification. ***Inspection Checklist:*** • Settings for ventilation system match baseline. • Mechanical parts, processes, and service area coverage for ventilation system meet specifications established in baseline conditions. • Barrier (foundation) is in similar condition to baseline conditions (compare to photos). • Source of "fresh air" is same as baseline. ***Alarm Test:*** • If system includes an alarm, test alarm to verify functionality (analogous to testing a smoke detector).	Complete pressure balancing as needed to re-establish a negative pressure in parking garage relative to overlying building. If ventilation control device fails or falls out of range of baseline condition, replace or repair to restore to baseline operating conditions. If ventilation rate, barrier, "fresh air" supply, or other site features essential to mitigation are changed from baseline conditions, evaluate and repair as needed to restore to baseline operating conditions. If baseline mitigating conditions (pressure or air exchange rate) cannot be reestablished, complete *Commissioning* procedures to verify performance and establish the new baseline conditions for the parking ventilation.
INDOOR AIR TREATMENT / EXCHANGER	***Indoor Air Verification Frequency:*** • At least once per year during heating season. • If a supplement to other mitigation control, complete concurrent with any other performance verification. ***Indoor Air:*** • Collected from location established during performance verification testing. • Indoor air remains below VALs.	***Maintenance Frequency:*** • At least once per year • More frequently as needed to replace filters or other treatment device ***Maintenance:*** • Replace filters or other treatment device • Any maintenance recommended by manufacturer	If indoor air exceeds VALs, replace or repair the air treatment control and retest the indoor air within 1 month of the repair. If indoor air cannot be restored to satisfy VALs, work with qualified professional to assess the vapor intrusion pathway for the property, and complete *Commissioning* for any new mitigation control to verify performance and establish the new baseline conditions.

NOTES:
(1) Long-term OM&M will often be the responsibility of the property owner. However, a qualified professional may be needed to complete the contingency action in many situations.
(2) The scope of the monitoring program will vary by site based on basis of mitigation design and commissioning results.
(3) The decision to include indoor air samples in the long-term monitoring will be made on case-by-case basis depending on building size, use, HVAC specifications, characteristics of vapor source, and whether or not the mitigation approach is stand-alone option or supplement to another mitigation strategy.

APPENDIX E – LONG-TERM OM&M GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and there is flexibility in the parameters and criteria used in a site-specific OM&M plan.
[2] Site-specific OM&M plans should demonstrate that the conditions proven to interrupt the vapor pathway during commissioning can be maintained in the future per Wis. Admin. Code § NR 724.13.

PASSIVE CONTROLS – LONG-TERM OM&M			
MITIGATION APPROACH	MONITORING	INSPECTION AND MAINTENANCE	CONTINGENCY(1)
PASSIVE VENTILATION	***Frequency:*** • At least four times per year • Include at least two events during heating season. • Include at least one event during high water conditions for sites with shallow water table. ***Vacuum:*** • Vacuum measured for each engineered vertical stack. • Measured at locations and devices established during commissioning (baseline conditions). Fixed devices are preferred. – Example: Vacuum measured using manometer, or similar device, with accuracy of 0.1 inch-H_2O mounted on conveyance pipe. • Vacuum measurements are within the range of vacuum established during commissioning (baseline conditions).	***Inspection & Maintenance Frequency:*** • At least once per year • Recommended to be concurrent with one depressurization verification event. ***Inspection Checklist:*** • Suction draw points and sumps remain sealed. • Barrier (foundation) is in similar condition to baseline conditions (compare to photos). • Conveyance pipe vents are clear. • Conveyance pipes are not damaged, cracked, or blocked. • Wind turbine fans, if used, remain free from obstructions and free to rotate. • Sub-slab probes (if present) are in good condition and remain capped/sealed.	Seal barrier, suction draw points, and sumps as needed to restore to baseline conditions or better. If vacuum measurements are outside of baseline range, troubleshoot to identify any leaks, high water, or vent blockage and repair to restore vacuum. If vacuum cannot be restored to tolerable range of baseline conditions, complete pressure field extension testing to verify depressurization. Upgrade system as needed to achieve pressure field extension (e.g. add fan to convert to active sub-slab depressurization). When system upgrade is needed, *Commissioning* procedures are completed to verify performance and establish the new baseline conditions
PASSIVE BARRIERS	It is expected that passive barriers will be used as stand-alone mitigation approach in rare situation when mitigation is required. This will likely be for situations with low-level impacts that are expected to attenuate to below risk screening levels within a short time periods. A site-specific long-term OM&M plan will need to be developed for this rare circumstance.		

NOTES:
(1) Long-term OM&M will often be the responsibility of the property owner. However, a qualified professional may be needed to complete the contingency action in many situations.
(2) The scope of the monitoring program will vary by site based on basis of mitigation design and commissioning results.
(3) The decision to include indoor air samples in the long-term monitoring will be made on case-by-case basis depending on building size, use, HVAC specifications, characteristics of vapor source, and whether or not the mitigation approach is stand-alone option or supplement to another mitigation strategy.

Appendix F
Decommissioning Guidelines

APPENDIX F– DECOMMISSIONING GUIDELINES [1, 2]

[1] These guidelines are only recommendations, and site-specific decommissioning plans will be necessary in most cases.
[2] Site- specific approaches should demonstrate that interruption of the vapor intrusion pathway is no longer needed per Wis. Admin. Code §§ NR 724.13 and 727.09(4) or 727.09(5).

<table>
<tr><th colspan="3">DECOMMISSIONING</th></tr>
<tr><th>MITIGATION APPROACH</th><th>SUBSURFACE VAPOR VERIFICATION PROCESS(2)</th><th>CONTINGENCY</th></tr>
<tr><td colspan="3">ACTIVE DEPRESSURIZATION</td></tr>
<tr><td>SUB-SLAB DEPRESSURIZATION</td><td>• Shut fan(s) off.
• Collect at least three rounds of sub-slab samples.
– First samples collected 2 to 4 weeks after shut-down.
– Second samples collected 2 to 6 months after shut-down.
– Third samples collected within 1 year of shut-down.
– At least two of the samples collected during heating season.</td><td rowspan="2">If concentrations of any sample exceed screening levels during decommissioning testing, restart fan(s), and return to Long-Term OM&M.

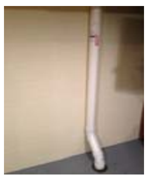
The amount of time to wait to restart the decommissioning process will depend on circumstances and concentrations detected in vapor samples.</td></tr>
<tr><td>SUBMEMBRANE DEPRESSURIZATION</td><td>• Shut fan(s) off.
• Collect at least three rounds of soil gas samples (see Sub-slab for criteria).
• Collect indoor air samples from crawl space concurrent with soil gas samples.</td></tr>
<tr><td colspan="3">ACTIVE INDOOR AIR CONTROLS</td></tr>
<tr><td>BDLG PRESSURIZATION</td><td rowspan="4">• Complete a sub-slab vapor investigation.</td><td rowspan="4">If concentrations of any sample exceed screening levels during decommissioning testing, return to Long-Term OM&M.

The amount of time to wait to restart the decommissioning process will depend on circumstances and concentrations detected in vapor samples.</td></tr>
<tr><td>HVAC OPTIMIZATION</td></tr>
<tr><td>PARKING GARAGE VENTILATION</td></tr>
<tr><td>INDOOR AIR TREATMENT/ EXCHANGE</td></tr>
<tr><td colspan="3">PASSIVE CONTROLS</td></tr>
<tr><td>PASSIVE VENTILATION</td><td rowspan="2">• Complete a sub-slab vapor investigation.
– If permanent sample probes were included in construction and maintained during Long-term OM&M, the subsurface vapor samples can be collected from these locations.
– If permanent sample probes are not present, evaluate best approach to sampling that will not compromise the integrity of the barrier.</td><td rowspan="2">If concentrations of any sample exceed screening levels return to Long-Term OM&M.

The amount of time to wait to restart the decommissioning process will depend on circumstances and concentrations detected in vapor samples.</td></tr>
<tr><td>PASSIVE BARRIERS</td></tr>
</table>

NOTES:
(1) Long-term OM&M will be the responsibility of the property owner after closure. However, a qualified professional will be needed to complete the decommission testing in most situations.
(2) The scope of testing completed during decommissioning aligns with criteria for a vapor investigation at the particular building type and land use setting (see Section 5).

Appendix G
Example OM&M Inspection Log

SYSTEM COMPONENT						ANNUAL INSEPECTION					
NAME	PHOTO	WHAT DOES IT DO?	WHAT DO I CHECK?	WHAT SHOULD I SEE?	WHAT TO FIX?						
Fan		Fan creates a vaccum and lowers pressure below foundation. The fan also removes soil gases from below foundation for discharge to atmosphere.	Fan Operation Fan Location Motor Noise	Fan is on Fan mounted outside & secure Fan motor is quiet (loud motor may indicate problem)	Fan may need to be replaced every 15 to 20 years. Replacement fan to have similar specifications as original with respect to flow and vacuum. **ORIGINAL = <u>Insert Fan Spec and Name</u>**	DATE	NOTES	DATE	NOTES	DATE	NOTES
Sealed Sump w/Vent Pipe		***Sump Cover***: Soil gases are collected in sump and the cover prevents soil gas from getting inside home. ***Vent Pipe:*** Pipe conveys the vacuum from the fan, and collects soil gases for discharge to the atmosphere.	Sump Cover Seal Vent Pipe Condition	Sump seal is air tight around edge and at pipe penetrations. Vent pipe is connected to fan, and is free of cracks or leaks.	Sump cover or vent pipe may need to be sealed or replaced if cracks or leaks appear. See **NOTE** below regarding pipe alternations. Have professional test pressures if pipes are modified	DATE	NOTES	DATE	NOTES	DATE	NOTES
Suction Drop Point w/Vent Pipe		***Suction Pit***: Soil gases are collected in a pit below the foundation, and tight seal prevents soil gas from getting inside home. ***Vent Pipe:*** Pipe conveys the vacuum from the fan, and collects soil gases for discharge to the atmosphere.	Suction Pit Seal Vent Pipe Condition	Seal is air tight around pipe penetration. Vent pipe is connected to fan, has not cracked	Suction pit seal or vent pipe may need to be sealed or replaced if cracks or leaks appear. See **NOTE** below regarding pipe alternations. Have professional test pressures if pipes are modified	DATE	NOTES	DATE	NOTES	DATE	NOTES
Manometer or Differential Pressure Gauge		Measures differential pressure between vacuum side of vent pipe and indoor space. This measurement confrims there is a vacuum being pulled by the fan.	Liquid Level on Manometer	Liquid level in manometer is between ___ and ___ on the ______-hand side.	A change in liquid level inidicates a change in the vacuum below foundation. This could be caused by failure of fan, blockage of vent pipe, change in water level below building, or other conditions. Troubleshoot or hire professional to identify cause and repair if needed.	DATE	MANOMETER LEVEL	DATE	MANOMETER LEVEL	DATE	MANOMETER LEVEL
Outdoor Vent Pipe		Pipe carries soil gas outside and vents them to the atmosphere.	Vent Pipe Condition Vent Pipe Location	Vent pipe remains connected to fan. End of pipe free from obstructions. The exhaust is more than 15 feet from windows or air intakes.	Vent pipe may require replacement, or cleaning to remove ice or debris. See **NOTE** below regarding pipe alternations. Have professional test pressures if pipes are modified.	DATE	NOTES	DATE	NOTES	DATE	NOTES
Foundation Floor		Foundation is a barrier that minimizes soil gas entry into building, and helps fan to work efficiently.	Foundation Condition Foundation Footprint	No penetrating cracks or holes in foundation below grade. Check if there have been alterations or additions to building.	Seal cracks or other penetrations as you would to prevent water from entering. If building floor plan has changed, contact a professional contractor and/or the DNR to evaluate if modifications to the vapor mitigation system are neccessary.	DATE	NOTES	DATE	NOTES	DATE	NOTES
Vapor Pin		This is a sample port to measure vacuum or take sample of soil gas if needed. It needs to remain sealed when not in use to prevent soil gas entry into the home.	Pin Seal/Cap Pin Condition	Vacuum measured with a micromanometer is less than ___ in H20 or ___ Pa. Pin is sealed and capped when not in use.	Repair or replace the seal and cover as needed. Permanantly seal hole if sample port is ever removed.	DATE	VACUUM (IN H20)	DATE	VACUUM (IN H20)	DATE	VACUUM (IN H20)

Appendix H

Vapor Intrusion Assessment Examples

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 1
CVOC CONTAMINATED SOIL BENEATH A COMMERCIAL BUILDING

CVOC CONTAMINATED SOIL BENEATH A COMMERCIAL BUILDING

A former dry cleaner operated in a strip mall for 20 years and a new tenant now occupies the space. Soil and groundwater impacts are defined and exist beneath several different commercial businesses in the strip mall. Groundwater monitoring indicates the plume is stable and naturally attenuating, and there is not a risk from direct contact to soil contamination. However, given the presence of PCE contamination in soil and shallow groundwater, it was determined that the vapor intrusion pathway needed further evaluation. Outreach is completed to inform the neighboring businesses about the on-going investigation. Sub-slab vapor sampling is completed at the former dry cleaner location.

- **Scenario A** – The sub-slab vapor concentrations are less than VRSLs for small commercial exposure scenario. Following 3 rounds of sub-slab sampling, it was concluded that the sub-slab vapor does not pose an exposure risk this case could close under NR 726. Closure conditions will include a requirement to notify the DNR prior to changing land use to determine if the exposure assumption at the time of closure still applies.

- **Scenario B –** The sub-slab vapor concentrations are greater than the small commercial VRSL for PCE. Additional sub-slab samples are collected to define the extent of vapor migration below the strip mall and along utilities that transect the source area. Sample results indicate that the sub-slab vapors over the VRSL for PCE are limited to the former dry cleaner. Indoor air samples are collected at the former dry cleaner after receiving the sub-slab sample results and all indoor air levels are less than non-residential VALs. All results are summarized and provided to the property owners, tenants, and DNR within 10 buisness days of receipt.

  While a current human health risk does not exist (based on PCE indoor air concentrations), the potential for a future health risk does exist (based on PCE in sub-slab vapors). Remedial action must be taken to reduce the mass and concentration of the source of contamination to the extent practical. After remediation is complete, sub-slab vapors are sampled again. If sub-slab concentrations remain over VRSLs after remediation, a sub-slab depressurization system (or other mitigation system) must be installed and operated to minimize worker and customer exposure to the contaminants in the future.

  Once performance of the mitigation system has been confirmed and a long-term OM&M Plan is in place, the requirements of NR 726 have been met and the site could be closed[1]. The current and future property owners will be responsible for the continued OM&M of the mitigation system. This site is a candidate for future environmental audits by the DNR to ensure the mitigation system remains operational.

- **Scenario C –** Same as Scenario B, but indoor air levels exceed the non-residential VAL for PCE. All the requirements to achieve closure listed in Scenario B apply to this scenario (e.g. remedial action, performance monitoring and OM&M Plan for mitigation system). However, this situation now represents an unacceptable inhalation exposure and action to mitigate or eliminate the exposure to contaminant vapors must be taken as soon as possible. DNR may contact DHS/local health for assistance in communicating the indoor air results to the occupants. Indoor air samples will be required after the mitigation system is operating to confirm that the indoor air concentrations have been reduced below VALs[2].

[1] As an alternative to installing a mitigation system, a long-term vapor monitoring program could be proposed. However, as long as sub-slab vapor concentrations remain above VRSLs and mitigation has not been implemented, closure is not possible. In accordance with Wis. Admin § NR 726.05(4), closure may not occur if at any time in the future the remaining level of contamination is likely to pose a threat to public health, safety, welfare or the environment.

[2] Off-gassing from concrete or building materials contaminated with PCE may be a source to indoor air concentrations at former dry cleaners. Additional cleaning of building materials may be needed to achieve VALs for these situations.

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 2
TCE GROUNDWATER PLUME WITH OFF-SITE MIGRATION ONTO RESIDENTIAL PROPERTIES

TCE GROUNDWATER PLUME WITH OFF-SITE MIGRATION ONTO RESIDENTIAL PROPERTIES

An industry discovers a discharge from one of their underground TCE tanks. The subsequent investigation determines that a plume of contaminated groundwater extends under an adjacent residential sub-division. The concentrations of TCE in the shallow groundwater exceed vapor screening criteria, and therefore the off-site vapor intrusion pathway needs to be evaluated as soon as possible. Three homes closest to the discharge are approached first for sub-slab vapor and indoor air sampling. Outreach is completed to inform the neighbors about the on-going investigation and to request access for sampling. Access agreements are established for the three homes.

During outreach, it is determined that a woman of child bearing age is living in one of the homes. The woman is referred to DHS for information on exposure risk to TCE during pregnancy. Concurrent sub-slab and indoor air samples are collected at the three homes as soon as possible after access agreements are in place. Samples are analyzed for CVOCs.

Note: In addition to the off-site vapor investigation, remedial action is planned for the source property.[3]

- **Scenario A –** The sub-slab vapor concentrations are less than VRSLs, and indoor air concentrations are less than VALs for CVOCs in a residential exposure scenario. The data is summarized and provided to the DNR and property owners within 10 days of receipt, and the next sampling event is scheduled with each homeowner for two to three months in the future. Concurrent sub-slab and indoor air samples are collected twice more (total of three events), and all measured concentrations are below VRSLs and VALs. The results are shared with DNR and homeowners within 10 days after receipt. The off-site vapor investigation is complete, assuming that the groundwater contaminant plume does not increase in concentration or extent.

- **Scenario B –** The sub-slab vapor concentrations exceed the VRSL for TCE, but indoor air concentrations are less than residential VALs for CVOCs. There is not an immediate risk, but vapor mitigation will be required on each of these homes, and additional investigation will be needed to define the extent of vapor migration. The RP provides home owners and DNR with results within 10 days of receipt, and offers to install a sub-slab depressurization system in each home to mitigate the potential for vapor intrusion. After the systems are installed, the pressure field extension is confirmed and a long-term OM&M plan is established for each home to ensure continued protection from the vapor pathway.

  The RP is responsible for OM&M of the mitigation systems until closure, and each property owner is responsible for OM&M of their system after closure. Depending on the results of the remedial action, additional vapor testing may be done in the future to confirm if vapor mitigation remains necessary after the remedial action is complete.

  In addition to mitigation, four homes on the next block are added to the vapor investigation, and concurrent sub-slab and indoor air samples are collected after access agreements are in place. Sampling results for homes on the next block match the summary provided in Scenario A, and the off-site vapor investigation is determined to be complete.

  CONTINUED ON NEXT PAGE ….

[3] The remedy for this site might include soil removal from the source area along with the installation of an active groundwater treatment and soil vapor extraction (SVE) system. As long as the groundwater treatment / SVE system needs to operate to control plume expansion, closure of the site is not possible. A vapor investigation must be completed on-site. In this case, the DNR approved doing the on-site vapor investigation after the remedial action is complete, if there is residual contamination.

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 2

TCE GROUNDWATER PLUME WITH OFF-SITE MIGRATION ONTO RESIDENTIAL PROPERTIES

… CONTINUED FROM PREVIOUS PAGE

- **Scenario C –** Same as Scenario B, except in this scenario the indoor air concentrations exceed the VAL for TCE in the home of woman of child-bearing age. All the requirements to achieve closure listed in Scenario B apply to this scenario (e.g. remedial action, performance monitoring and OM&M Plan for mitigation system). However, this situation represents an unacceptable inhalation exposure and action to mitigate the exposure to contaminant vapors should be taken as soon as possible.

  Results are shared with the DNR and homeowners within 10 days of receipt, and DNR contacts DHS/local health for assistance in communicating the indoor air results. A local health official follows up with the woman to answer her questions on risk of exposure to TCE vapor in the first trimester of pregnancy[4]. The responsible party offers to install a sub-slab depressurization system. During the commissioning of the system, indoor air sampling is required to confirm that the indoor air concentrations have been reduced below VALs.

- **Scenario D –** The sub-slab vapor concentrations are below the VRSLs, but the indoor air concentration is over tha VAL for TCE in one home. This situation represents an unacceptable inhalation exposure, but the source of the vapors does not appear to be from vapor intrusion. The results are shared with the homeowner and DNR within 10 days of receipt. The RP also provides the homeowners with a summary to explain why the TCE detected in indoor air is unlikely to be from vapor intrusion, and provides the contact information for DHS and/or local health official to answer health questions on risk of exposure to TCE. The next sampling event is scheduled for two to three months in the future, and the homeowner is given a list of potential sources of TCE and reminded to remove these items from the house at least 24 hours prior to sampling.

  The sub-slab concentrations are all below the VRSLs and indoor air concentrations are below VALs in the next two sampling events. The initial detection of TCE in indoor air is attributed to an indoor source, and the off-site vapor investigation is complete without the need for further testing or mitigation.

[4] If the woman was pregnant or to become pregnant, she may need to be relocated until indoor air concentrations are confirmed to be below the VAL for TCE.

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 3
PCE CONTAMINATION AT A DRY CLEANER STILL USING PCE

PCE CONTAMINATION AT A DRY CLEANER STILL USING PCE

An existing dry cleaner that still uses PCE in their operations recently completed a site investigation to define the degree and extent from a discharge of PCE at their current place of business. The investigation confirmed a small area of soil contamination directly under the building. Due to the presence of low permeability soils (primarily silt and clay) groundwater impacts have been minor and monitoring has determined that the contaminant plume is defined and is not expanding. Sub-slab sampling is conducted to evaluate whether vapor intrusion is a potential pathway of concern.

Note: Maintenance of the building cap for the soil and natural attenuation of groundwater were approved for this site.

- **Scenario A –** The sub-slab vapor concentrations are greater than the small commercial VRSL for PCE and the dry cleaner is in a strip mall. This is similar to Example 1-Scenaio B, but in this case it would be difficult to determine what affect vapor intrusion is having on the overall concentration of PCE in the building because of on-going dry cleaning operations. Additional sub-slab samples are installed at the two adjacent businesses to delineate vapor migration, and the concentrations were near, but below VRSLs after two sampling events.

  Although mitigation is not needed to achieve OSHA[5] standards within the dry cleaners, the owner installs a sub-slab vapor mitigation system to control lateral migration of soil gas toward neighboring businesses. Indoor air samples are not collected, but pressure field extension is completed to verify performance of the system and a long-term OM&M plan is put in place.

  The work and OM&M requirements for the system will be similar to Example 1- Scenario B, but this site will have an additional closure condition, which requires the owner to notify the DNR if the dry cleaner discontinues use of PCE or vacates the current building space. Once PCE is no longer used, indoor air samples would be required to determine whether there is a risk to human health using the non-residential VALs. The current and future property owners will be responsible for complying with the closure conditions, and this site is a candidate for future environmental audits by the DNR to ensure the compliance.

- **Scenario B –** The sub-slab vapor concentrations are greater than the small commercial VRSL for PCE and the operating dry cleaner is in a separate building over 100 feet from neighboring buildings. Mitigation is not needed for the dry cleaner to achieve OSHA standards or to control lateral vapor mitigation to neighboring buildings. Consideration was given to installing sub-slab vapor mitigation system now, so that the building is protected from vapor intrusion when the OSHA indoor standards are no longer applicable. However, in this case mitigation was not installed.

  Closure conditions will include a requirement to notify the DNR if the dry cleaner discontinues use of PCE or vacates the current building space. Once PCE is no longer used, indoor air and sub-slab vapor must be sampled to determine the need for additional actions. The current and future property owners will be responsible for complying with the closure conditions, and this site is a candidate for future environmental audits by the DNR to ensure the compliance.

  Because mitigation was not installed, if the vapor sampling completed after closure determines a health risk from vapor intrusion based on the non-residential VALs and VRSL, the DNR could reopen the site in accordance with Wis. Admin. § NR 727.13.

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[5] The OSHA indoor air quality standards that apply within the operating dry cleaner were not exceeded, based on sub-slab concentrations multiplied by the default attenuation factor.

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 4
REDEVELOPMENT OF A CVOC CONTAMINATED PROPERTY

REDEVELOPMENT OF A CVOC CONTAMINATED PROPERTY[6]

Residual TCE contamination is present in soil and shallow groundwater at a previously closed site that currently has no buildings and is undergoing redevelopment. (Site was able to be closed because a large portion of the source area was removed and groundwater monitoring showed the plume was receding.) The development plan calls for two mixed-use buildings to be constructed near the residual TCE contamination. One building will have below-grade parking with condominiums above grade, and the other will have condominiums constructed at-grade. The buildings will provide a direct contact barrier for the residual soil contamination.

Because both buildings are in areas that exceed vapor screening criteria for TCE, and so the developer includes vapor mitigation in the design for each building.[7] For one building, mitigation is the ventilation from an underground parking garage, which is designed to prevent air from within the garage from migrating into the overlying condos. For the second building, a vapor barrier and a passive soil gas venting system are installed, and the passive system is designed to easily be converted to an active depressurization system, if needed.

The scenarios below pertain to if vapor monitoring is completed after the buildings are constructed.

- **Scenario A –** Sub-slab samples are collected at both buildings three times prior to any active mitigation, and concentrations are all below the VRSL for a residential exposure scenario. The first sample round is collected 4 weeks after construction is complete, and two subsequent sample rounds are collected 2 and 5 months after construction, respectively. The developer voluntarily keeps the mitigating design features in the building, but the DNR does not require performance verification testing or long-term OM&M for the vapor mitigation systems, and the continuing obligation for vapor is removed from the property.

- **Scenario B –** Sub-slab vapor testing reveals that TCE exceeds the VRSL under both buildings for a residential exposure scenario.[8] Performance verification testing demonstrates that the parking garage ventilation is interrupting the vapor intrusion pathway to the overlying residential dwellings. For the second building, the developer converts the passive venting system to an active depressurization system by installing vacuum fans on the roof for each of the exhaust pipes. Performance verification testing finds that the active system maintains a negative pressure field under the entire building.

  Following performance verification, long-term OM&M plans are established for the parking garage ventilation and for the active depressurization system. Each plan explains how and why the system is needed to interrupt the vapor intrusion pathway. The DNR sets continuing obligations for the property under NR 726 for the continued OM&M of both systems, and annual submittal of inspection reports may be required. The current and future property owners will be responsible for the continued OM&M of the mitigation system. This site is a candidate for future environmental audits by the DNR to ensure the mitigation system remains operational,

- **Scenario C –** Sub-slab vapor samples are NOT collected after construction. Vapor intrusion remains a potential risk based on hydrogeologic conditions at the site, and therefore, all of the requirements described above in Scenario B are still required for this situation because sub-slab vapor samples were not collected.

[6] The post-closure modification process described in Wis. Admin. § NR 727 was followed during the redevelopment.
[7] Developers are encouraged to include mitigation in the design for new buildings if vapor intrusion is a potential risk. Installing mitigation design elements during construction is easier and often costs less than when they are retrofit after construction.
[8] If only one building had sub-slab concentrations over the VRSL for TCE, then performance verification, long-term OM&M, and continuation obligations would only be required on that one building.

APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

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EXAMPLE 5
PETROLEUM DISCHARGE WITH FREE-PRODUCT AND OFF-SITE MIGRATION OF GROUNDWATER

<u>PETROLEUM DISCHARGE WITH FREE-PRODUCT AND OFF-SITE MIGRATION OF GROUNDWATER</u>

An underground tank leaks at a service station releasing gasoline into fractured bedrock. The free product gasoline at the water table (~10 ft bgs) is the source of a shallow groundwater plume, which extends more than a city block downgradient of the service station. A local bank is the downgradient neighbor to the gas station, and further downgradient are residential dwellings. The concentration of benzene is over 1,000 μg/L in groundwater under three homes, but concentrations attenuate quickly and are less than 500 μg/L by the next block. The bank and three homes exceed the vapor screening criteria for PVOCs, and additional testing is planned to assess the vapor pathway. Outreach is completed to inform the bank and neighbors about the on-going investigation and to request access for sampling.

Note: In addition to the off-site vapor investigation, remedial action is planned for the source property (see Example 2)

- **Scenario A** – <u>Bank employees begin to complain of symptoms of burning eyes and an unusual odor in the basement</u>. A consultant evaluates the building and determines there is not an explosion hazard. Water samples collected from the sumps are analyzed and show that benzene concentrations exceed 1,000 μg/L. Results of indoor air sampling show benzene concentrations exceed the non-residential VAL for benzene. The data is summarized and provided to the DNR and property owners within 10 days of receipt, and the DNR contacts DHS/local health for assistance in communicating the indoor air results to the occupants.

  Due to the proximity of the groundwater to the basement foundation, a sub-slab depressurization system cannot be installed. The vapors appear to be emanating from the sumps; therefore the sumps are both sealed and vented to the outdoors. In addition, evaluation of the sumps confirms they are discharging the contaminated water to the sanitary sewer and not to the ground surface or storm sewer. Subsequent indoor air sampling confirms that benzene concentrations have fallen below the VAL, and follow up testing confirms that concentrations remain below the VAL throughout changing seasons. A long-term OM&M plan is developed to ensure that the sumps remained sealed and vapor vents are functional.

  The RP is responsible for maintenance of the system until closure, and depending on the results of the remedial action, additional vapor testing may be completed at the bank in the future to confirm if vapor mitigation remains necessary. Assuming mitigation remains necessary, the current and future property owners will be responsible for the continued OM&M of the sump seals after closure, and this site is a candidate for future environmental audits by the DNR to ensure the sumps remain sealed.
  (See Scenario D for discussion on residential properties over groundwater plume).

- **Scenario B –** The bank does not have a basement, and there are no obvious indoor odors, but the building is within 30 feet (laterally) of the free product. The consultant assesses the possible vapor pathway to the bank by conducting a survey of soil oxygen levels and soil benzene vapors between the bank and the free product zone. Soil gas samples are collected over depth intervals to assess the oxygen and vapor concentrations to depths within at least 5 feet below the foundation of the bank.

  The survey shows that soil oxygen levels are over 5%, methane is less than 1%, and benzene concentrations are near non-detect levels in the soil gas. The data is summarized and provided to the DNR and property owners within 10 days of receipt. The off-site vapor investigation is complete, assuming that the groundwater contaminant plume does not increase in concentration or extent during remedial action.
  (See Scenario D for discussion on residential properties over groundwater plume).

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APPENDIX H – VAPOR INTRUSION ASSESSMENT EXAMPLES [1]

[1] These examples do not include all the steps in the process and are *not* meant to be applied. The purpose of these examples is to highlight common situations, and may not account for all data used in a site-specific vapor assessment.

EXAMPLE 5
PETROLEUM DISCHARGE WITH FREE-PRODUCT AND OFF-SITE MIGRATION OF GROUNDWATER

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- **Scenario C –** The same circumstances as Scenario B, but soil gas samples show the oxygen levels in the soil are near zero within 5-feet of the foundation of the bank. Vapor intrusion cannot be ruled out using the screening criteria, and sub-slab vapor samples are collected from the bank and analyzed for PVOCs. The sub-slab vapors exceed the VRSL for benzene in a small-commercial exposure scenario. The data is summarized and provided to the DNR and property owners within 10 days of receipt.

  The responsible party provides the bank with an intrinsically safe (i.e. explosion proof) sub-slab depressurization system to mitigate potential risk from vapor intrusion. After start-up, the pressure field extension is confirmed and a long-term OM&M plan is established.

  The RP is responsible for maintenance of the system until closure, and depending on the results of the remedial action, additional vapor testing may be done on the bank in the future to confirm if vapor mitigation remains necessary. Assuming mitigation remains necessary, the current and future property owners will be responsible for the continued OM&M of the mitigation system after closure, and this site is a candidate for future environmental audits by the DNR to ensure the mitigation system remains effective.

  (See Scenario D for discussion on residential properties over groundwater plume).

- **Scenario D –**Residential homes overlying the groundwater contaminant plume with benzene over 1,000 μg/L. The homeowners do not complain of odors, but each homes has a basement and so the depth to the contaminated groundwater is less than 5 feet from the foundations. Additional sampling is needed to rule out the vapor pathway for these residential properties. As a first step, soil gas samples are collected over depth intervals to assess the oxygen and vapor concentrations to depths within 5-feet of the foundations of each basement. Soil oxygen levels are over 5%, methane is less than 1%, and benzene concentrations are below residential VRSL in all samples. Mitigation is not needed in the residential properties and the off-site vapor investigation is complete, assuming that the groundwater contaminant plume does not increase in concentration or extent during remedial action[9].

[9] In the event that sub-slab sampling was needed because soil gas samples had low oxygen and/or elevated benzene. The sampling requirements and response would be similar to those provided in Example 2.