



**NEW JERSEY DEPARTMENT OF
ENVIRONMENTAL PROTECTION
SITE REMEDIATION PROGRAM**

**VAPOR INTRUSION TECHNICAL
GUIDANCE**



January 2012
Version 2.0

New Jersey Department of Environmental Protection

Site Remediation Program

Vapor Intrusion Technical Guidance

January 2012

(Version 2)

ACKNOWLEDGEMENTS

The New Jersey Department of Environmental Protection (Department) Vapor Intrusion Technical Guidance (Version 2) document was prepared by the Department/Stakeholder Vapor Intrusion Guidance Committee in cooperation with the Department Vapor Intrusion Committee.

Department/Stakeholder Vapor Intrusion Guidance Committee

John Boyer, Chair, New Jersey Department of Environmental Protection
Buddy Bealer, Shell
Ken Bird, Cummings Riter Consultants
Brian Blum, Langan Consultants
Michael Draikiwicz, Novartis
Scott Drew, Geosyntec Consultants
Diane Groth, New Jersey Department of Environmental Protection
Peter Sorge, JM Sorge, Inc., Environmental Consultants
Chad Van Sciver, New Jersey Department of Environmental Protection

Department Vapor Intrusion Committee

Diane Groth, Chair	Joseph Stefanoni
John Boyer	Heather Swartz
Tracy Grabiak	Chad Van Sciver
Paul Sanders	

Technical Reviewers outside the Department (for 2009 draft document):

David Folkes, EnviroGroup Limited
Blayne Hartman, Hartman Environmental Geoscience
Todd McAlary, Geosyntec Consultants
Bill Morris, Vapor Mitigation Sciences
Gina Plantz, Haley & Aldrich Consultants
Rich Rago, Haley & Aldrich Consultants

Special thanks for the assistance of the following individuals from the Department:

Linda Cullen
Barry Frasco
David Haymes
Kathy Kunze
George Nicholas
Kathy Pietras
Kevin Schick

Cover graphic courtesy of the Interstate Technology & Regulatory Council (ITRC).

DISCLAIMER

The use of any trade names, products or materials in this document does not constitute an endorsement by the State of New Jersey's Department of Environmental Protection (Department).

The information in the Department's Vapor Intrusion Technical Guidance (Version 2) document is provided free of charge to the public. The State of New Jersey, its agencies and employees assume no responsibility to any person or entity for the use of this information. There are no representations or warranties, expressed or implied, of any kind with regard to this information, and any use of this information is made at the risk of the user.

Neither the Department nor the State of New Jersey maintains many of the web links and web addresses in the Department's Vapor Intrusion Technical Guidance (Version 2). The Department makes no special endorsement for the content of these links, their sites or the views expressed by the sites' publishers.

Web sites may change or remove their contents at any time. Therefore, the Department cannot guarantee that the material on the referenced Web sites will be the same as it was when the Vapor Intrusion Technical Guidance (Version 2) was developed or even that the links will be available.

Trademarks (e.g., Microsoft Works, Adobe Acrobat) belong to their respective companies.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS..... *ii*

DISCLAIMER *ii*

TABLE OF CONTENTS..... *iii*

EXECUTIVE SUMMARY *1*

1.0 INTRODUCTION *2*

 1.1 *Intended Use of this Technical Guidance* *2*

 1.2 *Regulatory Basis for this Technical Guidance*..... *2*

 1.3 *Overview of this Guidance*..... *3*

 1.4 *Guidance Updates*..... *4*

2.0 DECISION FRAMEWORK..... *5*

 2.1 *VI Investigation Triggers* *5*

 2.2 *Vapor Intrusion Screening Levels*..... *6*

 2.2.1 *Ground Water Screening Levels*..... *6*

 2.2.2 *Soil Gas Screening Levels*..... *7*

 2.2.3 *Indoor Air Screening Levels* *7*

 2.3 *VI Receptor Evaluation (Stage 1)* *8*

 2.3.1 *Initial Data Gathering* *8*

 2.3.2 *Building and Structures* *9*

 2.4 *VI Investigation (Stage 2)* *10*

 2.4.1 *Investigative Approach* *10*

 2.4.2 *Iterative Nature of VI Investigations*..... *11*

 2.4.3 *Critical Distance Criteria* *12*

 2.4.4 *Data Usability*..... *12*

 2.4.5 *Site-Specific Options*..... *13*

 2.5 *Mitigation (Stage 3)* *15*

 2.5.1 *Vapor Concern*..... *15*

 2.5.2 *Vapor Intrusion Immediate Environmental Concern*..... *15*

 2.5.3 *Institutional Controls and Future Use*..... *16*

 2.6 *Operation, Maintenance and Monitoring (Stage 4)*..... *16*

 2.7 *Termination (Stage 5)* *16*

3.0 INVESTIGATIVE APPROACHES..... *17*

 3.1 *Conducting a Vapor Intrusion Investigation* *17*

 3.1.1 *Conceptual Site Model*..... *17*

 3.1.2 *Investigative Tools*..... *17*

 3.1.2.1 *Ground Water Sampling* *17*

 3.1.2.2 *Soil Gas Sampling*..... *18*

 3.1.2.3 *Indoor Air Sampling* *20*

 3.1.2.4 *Soil Sampling* *21*

 3.1.2.5 *Other Investigative Tools*..... *21*

 3.1.3 *Preferential Pathways* *22*

3.1.4	Landfills and Methane Gas	23
3.1.4.1	Methane	23
3.1.4.2	Landfill Gases	23
3.1.4.3	Landfill Gas Production and Flow	24
3.1.4.4	Landfill Building Requirements	25
3.1.4.5	Methane Investigations and Analytical Methods	25
3.2	Ground Water Investigation and Sampling.....	27
3.2.1.	Saturated Zone Features Affecting Vapor Intrusion.....	27
3.2.1.1	Clean Water Lens.....	28
3.2.1.2	Depth to Saturated Zone and Stratigraphy.....	28
3.2.1.3	Fluctuation in Depth to Saturated Zone.....	29
3.2.1.4	Complex Hydrogeologic Settings.....	29
3.2.1.5	Proximity to Preferential Pathways.....	29
3.2.1.6	Potential for Contaminant Degradation	29
3.2.2	Use of Pre-Existing Ground Water Data.....	30
3.2.2.1	Interpolation of Nearby Data.....	30
3.2.2.2	Use of Drinking Water Well Data.....	30
3.2.3	Obtaining New Ground Water Data to Evaluate the VI Pathway	30
3.2.3.1	Sampling Depth Interval Guidance for Multiple Sampling Methods.....	31
3.2.3.2	Direct Push and Alternative Ground Water Sampling Methods.....	32
3.2.3.3	Ongoing Ground Water Monitoring	32
3.3	Soil Gas Sampling.....	32
3.3.1	Sub-Slab Soil Gas Sampling.....	33
3.3.1.1	Application.....	33
3.3.1.2	Investigative Considerations.....	33
3.3.1.3	Analytical Methods and Parameters.....	34
3.3.1.4	Leak Check.....	35
3.3.1.5	Sample Flow Rate	36
3.3.1.6	Calculating Purge Volumes	37
3.3.1.7	Number and Location of Sample Points.....	37
3.3.1.8	Sample Frequency.....	39
3.3.2	Alternative Soil Gas Sampling.....	39
3.3.2.1	Application.....	39
3.3.2.2	Investigative Considerations and Procedures	40
3.3.2.3	Number and Location of Samples	40
3.3.2.4	Undeveloped Parcels and Future Use	41
3.4	Conducting a Building Walkthrough and Survey.....	41
3.4.1	Identification of Potential Background Sources	42
3.4.2	Recognition of Points of Vapor Intrusion in a Building	42
3.4.3	Identification of Possible Sample Locations.....	43
3.4.4	Education of the Occupants on Vapor Intrusion and Sampling Procedures	43
3.5	Indoor Air Sampling.....	43
3.5.1	Application.....	43
3.5.2	Investigative Considerations.....	44
3.5.3	Parameters.....	45
3.5.4	Sample Duration and Flow Rate	46
3.5.5	Number and Location of Samples	46
3.5.6	Sample Events.....	48
3.6	Investigative Reporting Requirements	49
3.6.1	VI Receptor Evaluation.....	49
3.6.2	VI Sampling	50
3.6.3	Immediate Environmental Concerns.....	50
4.0	MULTIPLE LINES OF EVIDENCE AND DATA EVALUATION	52
4.1	Background Indoor Air Sources.....	52

4.2	<i>Components of a Multiple Lines of Evidence Approach</i>	53
4.2.1	<i>Primary Factors</i>	53
4.2.1.1	<i>Site-Specific Contaminants of Concern</i>	53
4.2.1.2	<i>Sub-slab soil gas sampling</i>	54
4.2.1.3	<i>Ambient (outdoor) air sampling</i>	54
4.2.1.4	<i>Indoor air background databases</i>	55
4.2.2	<i>Secondary Factors</i>	55
4.2.2.1	<i>Building survey</i>	55
4.2.2.2	<i>Exterior soil gas sampling</i>	56
4.2.2.3	<i>Building Characteristics</i>	56
4.2.2.4	<i>Soil Properties</i>	56
4.3	<i>Data Evaluation</i>	57
4.3.1	<i>Background Sources</i>	57
4.3.2	<i>Ground Water Samples</i>	57
4.3.3	<i>Multi-Depth Ground Water Contaminant Data</i>	58
4.3.4	<i>Sub-Slab Soil Gas Samples</i>	58
4.3.5	<i>Indoor Air Samples from the Basement</i>	59
4.3.6	<i>Multiple Indoor Air Samples from Different Floors</i>	59
4.3.7	<i>Indoor Air and Sub-Slab Soil Gas Samples</i>	60
4.4	<i>Compliance</i>	62
4.5	<i>Official Notification</i>	62
5.0	<i>PETROLEUM HYDROCARBONS</i>	63
5.1	<i>Introduction</i>	63
5.2	<i>Biodegradation</i>	63
5.3	<i>VI Investigation</i>	64
5.4	<i>Alternative Approaches</i>	65
5.4.1	<i>Gasoline Discharges</i>	65
5.4.1.1	<i>Gasoline Exclusion Criteria</i>	65
5.4.1.2	<i>Conditions for Application of Gasoline Exclusion Criteria</i>	66
5.4.1.3	<i>Collecting O₂, CO₂, CH₄ for Application of Gasoline Exclusion Criteria</i>	66
5.4.2	<i>Discharges of No. 2 Fuel Oil / Diesel Fuel Oil & Heavier Petroleum Fractions</i>	66
6.0	<i>VAPOR INTRUSION MITIGATION</i>	68
6.1	<i>Initial Response Actions – Overview and Timeframes</i>	68
6.1.1	<i>Response Action Categories</i>	68
6.1.1.1	<i>Immediate Environmental Concern</i>	68
6.1.1.2	<i>Vapor Concern</i>	68
6.1.1.3	<i>Emergency Response Action</i>	69
6.1.1.4	<i>VI Contamination Unrelated to Site Being Investigated</i>	69
6.1.2	<i>Specific Response Actions</i>	69
6.1.2.1	<i>Department Notification</i>	69
6.1.2.2	<i>Interim Response Action (IRA)</i>	69
6.1.2.3	<i>VC Mitigation Plan</i>	70
6.1.2.4	<i>Engineered System Response Action (ESRA)</i>	71
6.2	<i>Mitigation Methods</i>	71
6.2.1	<i>Active Subsurface Depressurization Systems</i>	72
6.2.2	<i>Passive Subsurface Depressurization Systems</i>	73
6.2.3	<i>Sub-Slab Ventilation Systems</i>	74
6.2.4	<i>Alternative Mitigation Methods</i>	74
6.3	<i>Mitigation System Design and Construction</i>	75
6.3.1	<i>System Design and Installer Qualifications</i>	75
6.3.2	<i>Pre-Mitigation Diagnostic Testing</i>	76

	6.3.2.1	Visual Inspection.....	76
	6.3.2.2	Backdrafting.....	76
	6.3.2.3	Stack Effects.....	77
	6.3.2.4	Communication Test.....	77
	6.3.2.5	Permanent Sub-slab Soil Gas Probes.....	77
	6.3.2.6	Condensation.....	77
	6.3.2.7	Alarms.....	78
	6.3.3	Sealing Vapor Entryways.....	78
	6.3.4	Gas Vapor Barriers.....	79
	6.3.5	Construction and Electrical Permits.....	80
	6.3.6	Air Permits.....	81
	6.3.7	Buildings with Existing Radon Systems.....	81
6.4		Post-Mitigation Activities.....	81
	6.4.1	Institutional and Engineering Controls.....	81
	6.4.2	System Commissioning (Post-Mitigation Diagnostic Test).....	83
	6.4.2.1	Vapor Intrusion Mitigation System Inspection Checklist.....	83
	6.4.2.2	Active System Diagnostic Measurements.....	83
	6.4.2.3	Passive System Diagnostic Measurements.....	84
	6.4.2.4	Subsurface Vacuum Measurements.....	84
	6.4.2.5	Backdraft Testing.....	85
	6.4.2.6	Building Owner Notification of System Operations.....	85
	6.4.2.7	Conversion Factors.....	85
	6.4.3	Verification Sampling.....	86
	6.4.4	Engineered System Response Action Report.....	86
6.5		Operation, Maintenance and Monitoring.....	87
	6.5.1	Variations in Baseline Parameters.....	88
	6.5.2	Long-Term Monitoring.....	90
6.6		System Termination.....	91
 REFERENCES.....			 92

TABLES

Table 3-1	<i>Recommended Minimum Number of Sub-Slab Soil Gas Samples</i>	38
Table 3-2	<i>Recommended Minimum Number of Indoor Air Samples</i>	47
Table 4-1	<i>Illustrative Example of Sub-Slab Soil Gas and Indoor Air Results</i>	62
Table 6.1	<i>Unit Conversions for VI Mitigation</i>	86
Table 6.2	<i>Vapor Mitigation Verification and OMM Criteria</i>	90
Table 6.3	<i>Long Term Monitoring Sampling Designs</i>	91

FIGURES

Figure 2-1	<i>Soil Classification System</i>	15
Figure 3-1	<i>Schematic Diagram of Sampling Train using Leak Detection and Photograph of Helium Shroud with Summa Canister</i>	36
Figure 5-1	<i>Petroleum VI Conceptual Site Model</i>	65

APPENDICES

APPENDIX A *Decision Flow Chart*

APPENDIX B *Vapor Intrusion Timeline*

APPENDIX C *ITRC Conceptual Site Model Checklist*

APPENDIX D *Indoor Air Building Survey and Sampling Form*

APPENDIX E *Evaluating Indoor Air near VOC Contaminated Sites fact sheet*

APPENDIX F *Instructions for Occupants - Indoor Air Sampling Events (English and Spanish)*

APPENDIX G *Background Volatile Levels in Homes: Literature Review*

APPENDIX H *Common Background Indoor Air Sources*

APPENDIX I *Simple Smoke Visualization Test to Assess Backdrafting*

APPENDIX J *Installation Procedures of Permanent Sub-slab Probes for Monitoring VI Mitigation Systems*

APPENDIX K *Decision Flow Chart for Air Pollution Control Permit*

APPENDIX L *Determining Air Pollution Control Permit Requirement*

APPENDIX M *Vapor Intrusion Mitigation System Inspection Checklist*

APPENDIX N *Subsurface Depressurization Monitoring Form (Large Blower)*

APPENDIX O *Subsurface Depressurization Monitoring Form (Small Blower)*

APPENDIX P *Electrical Cost Estimates for Subsurface Depressurization Systems*

APPENDIX Q *Glossary*

APPENDIX R *Acronyms*

EXECUTIVE SUMMARY

Vapor Intrusion (VI) is defined as the migration of volatile chemicals from the subsurface into overlying buildings (USEPA 2002b). The presence of volatile compounds in soil or ground water offers the potential for chemical vapors to migrate through subsurface soils and along preferential pathways, potentially impacting the indoor air (IA) quality of affected buildings.

The Vapor Intrusion Technical (VIT) Guidance is designed to help the investigator to comply with the requirements of the New Jersey Department of Environmental Protection (Department) and properly assess the VI pathway. The technical guidance takes the investigator through the various stages of receptor evaluation, VI investigation, mitigation, monitoring and ultimately termination.

Basic concepts, such as conceptual site models (CSM) and multiple lines of evidence (MLE), are presented and their application to the VI assessment are explained. The VIT Guidance provides recommended protocol for investigating the VI pathway, including the recommended number of sub-slab soil gas (SSSG) and IA samples based on the size of the building footprint and numerous other technical factors.

IA analytical results are compared to the Indoor Air Screening Levels (IASL) and the Rapid Action Levels (RAL). An immediate environmental concern (IEC) is present when VI related IA concentrations exceed the RAL, the source of the exceedance is due to a discharge, and a completed pathway for VI has been confirmed. Whereas, if VI related IA concentrations exceed the IASL, but are equal to or less than the RAL, a vapor concern (VC) exists.

Specific gasoline exclusion criteria are presented to address the unique nature of these petroleum hydrocarbons. The investigator is provided detailed information on data review and the complex nature of background sources on the interpretation of analytical results.

Design, mitigation and post-mitigation procedures are thoroughly discussed and the appropriate monitoring provisions are outlined.

The Department's VI screening levels are located in Tables 1 through 3 on the Department's VI website at <http://www.nj.gov/dep/srp/guidance/vaporintrusion/>.

1.0 INTRODUCTION

VI has been recognized as a potential exposure pathway for human health risks for over two decades. VI is defined as the migration of volatile chemicals from the subsurface into overlying buildings (USEPA 2002b). The presence of volatile compounds in soil or ground water offers the potential for chemical vapors to migrate through subsurface soils and along preferential pathways, potentially impacting the IA quality of affected buildings. The accumulation of volatile vapors in impacted buildings can result in acute or chronic human health concerns.

1.1 Intended Use of this Technical Guidance

The Vapor Intrusion Technical (VIT) Guidance is designed to help the person responsible for conducting remediation to comply with the requirements of the New Jersey Department of Environmental Protection (Department) established by the Technical Requirements for Site Remediation (Technical Rules), New Jersey Administrative Code (N.J.A.C.) 7:26E. Specifically, the technical guidance is intended for use in the evaluation of the VI pathway at primarily volatile organic compound (VOC) contaminated sites located within the state of New Jersey. While this document concentrates on VOC contaminated sites, evaluation of other volatile compounds (e.g., formaldehyde, naphthalene, mercury) for the VI pathway may be necessary to protect public safety, health and the environment.

Individuals involved in using this guidance may include licensed site remediation professionals (LSRP), non-LSRP environmental consultants, Department personnel, and other environmental professionals. Therefore, the generic term “investigator” will be used to refer to any person that uses this guidance on behalf of a remediating party, including the remediating party itself.

In applying technical guidance, the Department recognizes that professional judgment may result in a range of interpretations on the application of the guidance to site conditions. If the investigator does not consider this technical guidance appropriate or necessary, the investigator must explain why and provide adequate justification to document that the decisions made are still protective of public health, safety and the environment. The procedures for a person to vary from the Technical Rules in regulation are outlined at N.J.A.C. 7:26E-1.7 and further clarified at http://www.nj.gov/dep/srp/srra/training/matrix/important_messages/variance_and_bpj.pdf.

This document updates and replaces the Department’s Vapor Intrusion Guidance, October 2005 (NJDEP 2005b) and supersedes other related technical guidance on this topic.

1.2 Regulatory Basis for this Technical Guidance

The legal basis for the evaluation of the VI pathway associated with contaminated sites is rooted in various statutes and regulations that include, but are not limited to, those outlined below.

The Brownfields and Contaminated Sites Act specifies that “the State needs to ensure that the public health and safety and the environment are protected from the risks posed by contaminated sites....” N.J.S.A. 58:10B-1.2. The presence of subsurface volatile contamination offers the potential for area buildings to be impacted through the VI pathway. The evaluation of these risks

should include consideration of the potential for vapor migration to impact the IA quality of a building and the health of the people in the building.

The Site Remediation Reform Act (SRRA) provides the basis for the LSRP program where the LSRP must ensure that a remediated site is “in compliance with all applicable statutes, rules and regulations protective of public health and safety and the environment.” N.J.S.A. 58:10C-14d. SRRA defines “confirmed contamination that has migrated into an occupied or confined space producing a toxic or harmful atmosphere resulting in an unacceptable human health exposure...” (N.J.S.A. 58:10C-2) as a condition that represents an IEC for the VI pathway that must be addressed pursuant to the Technical Rules. The application of this technical guidance in the evaluation of the VI pathway is included in SRRA, which requires an LSRP to “apply any available and appropriate technical guidelines concerning site remediation as issued by the department.” N.J.S.A. 58:10C-14c(3).

The Department’s Technical Rules, in N.J.A.C.7:26E-1.18, specify the requirement to evaluate the VI pathway. The requirements associated with an IEC for the VI pathway are presented in N.J.A.C.7:26E-1.14. Section 8.3 and 8.6 of the Technical Rules outline ground water classification exception area (CEA) requirements that address the VI pathway.

1.3 Overview of this Guidance

This technical guidance incorporates a risk-based, staged approach to evaluate the potential for VI associated with contaminated sites. The document has been developed after consideration of the latest state of the science procedures and methodologies currently included in the United States Environmental Protection Agency (USEPA), ASTM, Interstate Technology and Regulatory Council (ITRC), State and industry guidance that address the VI pathway. While the Department has incorporated many of the latest recommended methodologies in the document, New Jersey specific characteristics, input parameters and procedures have also been included, where applicable.

The investigator’s strategy for the VI pathway should consist of a series of stages designed to consistently and logically progress through the process of

VI Pathway Investigative Strategy

Stage 1: VI Receptor Evaluation

Assess potential for VI
Identify receptors

Stage 2: VI Investigation

Develop and implement VI Investigation
Evaluate data using applicable screening levels

Stage 3: Mitigation

Determine appropriate mitigation
Implement mitigation

Stage 4: Operations, Maintenance and Monitoring

Establish a long-term monitoring/
maintenance program

Stage 5: Termination

Assess ability to terminate mitigation

assessing the potential for VI. These stages are structured in this guidance to be consistent with the organization of a typical investigation as required in the Technical Rules. In addition, the *Decision Flow Chart* (Appendix A) and the *Vapor Intrusion Timeline* (Appendix B) should be consulted when assessing the VI pathway.

While this guidance discusses typical situations that an investigator may encounter while assessing the VI pathway, it is not comprehensive, nor inclusive of all potential scenarios and related investigative tools involving VI.

1.4 Guidance Updates

The Department will update the document as the state of the science for VI pathway evaluation advances. The current document along with updates to the screening levels and other sections of the document are, or will be, presented on the Department's website at www.state.nj.us/dep/srp/guidance/vaporintrusion/. It is recommended that investigators refer to the NJDEP website to ensure that they are using the most current information in the evaluation of a site. In addition, information on community outreach, sample result letters and tables, as well as access letters can be found on the Department's VI website.

2.0 DECISION FRAMEWORK

The *Decision Flow Chart* (Appendix A) is designed to assist the investigator in assessing the appropriate steps when evaluating the VI pathway. The chart was formulated to address most situations where suspected IA impacts may be occurring due to sources from soil or ground water contamination, or known spills inside a building. Use professional judgment for any circumstances that are unique or present complex problems not fitting the paradigm.

The technical guidance utilizes a phased approach for investigating the VI pathway. This framework follows the basic provisions of the USEPA Subsurface Vapor Intrusion Guidance (2002b) and various state VI guidance documents. Refer to Sections 2.3 through 2.7 (below) for further discussion on the phased approach.

The decision framework starts with the VI receptor evaluation which encompasses the data gathering phase associated with a preliminary assessment and site investigation. The VI investigation stage involves comparing the Department's screening levels to analytical data from IA, SSSG and ground water samples, as well as other lines of evidence, to resolve whether there is the potential for this pathway to be complete. Site-specific parameters or alternative sampling approaches may be used as part of the VI investigation.

The mitigation stage addresses potential mitigation actions, while the Operation, Maintenance and Monitoring (OMM) phase deals with ongoing post-mitigation requirements. Provisions dealing with the conclusion of the VI pathway are handled in the termination stage.

2.1 VI Investigation Triggers

The most basic question an investigator asks when considering VI is "When do I have to investigate this pathway?"

Ground water in excess of the NJDEP Ground Water Screening Levels (GWSL) is a potential source of VI that can adversely impact the IA quality of nearby buildings. Additional assessment shall be conducted when a building is located within the critical distance criteria (N.J.A.C. 7:26E-1.18). Buildings and structures are more fully described in Section 2.3.2 and further clarification on the critical distance criteria can be found below in Section 2.4.3.

Existing soil gas or IA data are compared to the Department's Soil Gas Screening Levels (SGSL) and IASL, respectively. An exceedance of these screening levels will necessitate further evaluation and possible mitigation of the VI pathway (per N.J.A.C. 7:26E-1.18).

Additional factors that trigger a VI investigation (N.J.A.C. 7:26E-1.18) are as follows:

- A landfill located on or adjacent to the site (refer to Section 3.1.4);
 - A wet basement or sump in a building containing free product and/or ground water with any detectable levels of a volatile contaminant;
 - Methanogenic (methane generating) conditions are present that may cause an explosion;
- or

- Any other information that indicates human health may be impacted via the VI pathway (e.g., volatile soil contamination near or under a building).

The Department currently does not have soil screening levels for the VI pathway. Therefore, the investigator should determine – based on their professional judgment – whether to investigate contaminated soils identified in the unsaturated zone near a building as part of the VI pathway. A site-specific evaluation should consider the volatile contaminant concentrations in soil, how close the contaminated soil is to a building and the utilities that serve it, and whether the contaminants are readily biodegradable or more recalcitrant. Another consideration would be the ultimate remedial action for the contaminated soils (e.g., removed versus remaining in place). The investigator should assess these and other site-specific factors when determining whether the VI pathway should be investigated (if only soil data are available). The Department’s soil remediation standards should not be utilized in this determination because the standards were not developed for the VI pathway.

2.2 Vapor Intrusion Screening Levels

The investigator should be gathering and evaluating any existing sampling results or other data to assess the VI pathway relative to the Department’s screening levels to determine whether the VI pathway triggers investigation or mitigation. The Department has developed these screening values for ground water, IA and soil gas. The Department’s VI screening levels are located in Tables 1 through 3 on the Department’s VI website at <http://www.nj.gov/dep/srp/guidance/vaporintrusion/>.

2.2.1 Ground Water Screening Levels

Ground water data shall be compared to the Department’s GWSL in Table 1 of the Department’s VI website (N.J.A.C. 7:26E-1.18). The GWSL may be used in the evaluation of a site where the ground water is as close as two feet below the building slab when: 1) the seasonal high water table does not reach the building slab; 2) the water table does not extend into fill material directly under the building slab; and 3) the top of the capillary zone does not reach the building slab.

The capillary zone does not normally extend through the base course layer under the slab. For situations where no fill material is present under a building’s slab, estimate the top of the capillary zone based on the anticipated soil texture present. Based on an evaluation of the various soil types using the Johnson & Ettinger (J&E) model (Johnson & Ettinger, 1991), the capillary zone, necessary to address item 3 above, has been determined to be greater than two feet in height for finer soils. As a result, the distance between the water table and the building slab should be at least 2.7 feet for clay soils, 4.4 feet for silty clay loam, 5.3 feet for silt and 6.3 feet for silty clay soils. Site-specific field determinations may be made in these circumstances for soil texture.

Provided the above conditions are met, the Department’s GWSL are appropriate for use at sites where unsaturated soil is present below the building slab. If the conditions above are not met, the Department’s GWSL should not be utilized in assessing the VI pathway.

GWSL should also not be applied where a building slab is in direct contact with competent, massive bedrock containing discrete fractured zones as vertical fractures are very likely to act as preferential pathways for vapors (e.g., creating a direct pathway for vapors between the ground water table and the building slabs). Use the GWSL for soils that contain gravel, assuming they exhibit relatively homogeneous, isotropic conditions.

Apply the GWSL where the water table is in bedrock and nearby site-specific data indicate there is unsaturated soil, fill or geologic material below a building slab through which subsurface air flow would approximate, or approach, porous media conditions. In many areas bedrock in the vadose zone and at the water table is so highly weathered and/or densely fractured that these conditions will be met even if deeper, more competent bedrock creates very heterogeneous flow conditions.

In situations where it is inappropriate to utilize the GWSL, the investigator should employ other lines of evidence (e.g., SSSG, near slab soil gas and IA samples) as discussed in Sections 3.3 & 3.5 of this document and Vapor Intrusion Pathway: A Practical Guideline (ITRC 2007).

2.2.2 Soil Gas Screening Levels

The Department's SGSL in Table 1 shall be compared to the sub-slab and/or near slab soil gas results (N.J.A.C. 7:26E-1.18). Use the SGSL in the evaluation of representative and appropriate (see Chapter 3) soil gas analytical results. Exceedance of the SGSL indicates the potential for VI that necessitates further evaluation of the pathway as outlined in Chapter 4 of this guidance. Soil gas results that do not exceed the SGSLs may or may not suggest further investigation. Refer to Section 3.1.2.2 for additional information.

2.2.3 Indoor Air Screening Levels

The results of IA samples shall be compared to the Department's IASL listed in Table 1 (N.J.A.C. 7:26E-1.18). The table presents residential and nonresidential IASL that are used in the evaluation of IA analytical results collected from within a building. Consistent with the Department's Remediation Standards (N.J.A.C. 7:26D), the Department requires use of the residential IASL in the evaluation of residential properties, schools and child care centers.

The nonresidential IASL are applicable to industrial/commercial facilities where the adult is the receptor of concern, a discharge to the environment has occurred and the facility (or portion of the facility) is not currently handling or using the subsurface contaminants of concern (COCs) associated with the discharge. While the collection of IA samples is generally not recommended in situations where the facility is currently using the same COC for the VI pathway, IA samples collected under these circumstances should include consideration of both the nonresidential screening levels and the applicability of the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PEL) to the subject building.

Air samples collected from a building crawlspace are also compared to the applicable residential or nonresidential IASL to determine whether further investigation is necessary (e.g., collecting IA samples from the living space above the crawlspace). The subsequent IA sample results are

then compared to the applicable IASL to determine whether an IEC or VC condition for the VI pathway exists within the building (as discussed below).

A VC or IEC does not exist at a building (or portion of a building) when OSHA applicability has been determined. This position assumes that the workers in question are fully covered by OSHA regulations (e.g., notification, training in personal protective clothing and gear, medical monitoring, documentation). The investigator should document the use of the OSHA PELs.

Consider and address the potential for a future change in the use of the building or in the use of the COC within the building in situations wherein nonresidential IASL and/or the OSHA PEL are used. Periodic verification of both the use of the building and the COCs will be necessary as part of institutional control requirements at the affected building(s).

The evaluation of IA data collected at a site shall also include a determination as to whether an IEC for the VI pathway exists in a building (N.J.A.C. 7:26E-1.18). An IEC determination is based on 1) an exceedance of the applicable RAL found in Table 2 of the Department's VI website (<http://www.nj.gov/dep/srp/guidance/vaporintrusion/>) and 2) the conclusion that the exceedance is resulting from a completed VI pathway and not principally background or ambient air sources. The Department shall be contacted to identify an applicable RAL should a value not be listed for a COC in Table 2 (N.J.A.C. 7:26E-1.14(b)5).

A potentially explosive environment present in a building or subsurface utility is not an IEC, but rather an emergency situation. Thus, a potentially explosive condition shall be immediately reported to 911, the Department's Hotline and the New Jersey Department of Health and Senior Services (NJDHSS) irrespective of the source.

Health Department Notification Levels (HDNL), developed in consultation with NJDHSS, are listed in Table 2 (<http://www.nj.gov/dep/srp/guidance/vaporintrusion/>) of the Department's VI website. These values, when exceeded in occupied buildings, indicate the need for the investigator to inform the NJDHSS, the Department and the local health department, by telephone about the site and the associated VI related IA concentrations for further evaluation and possible emergency actions.

2.3 VI Receptor Evaluation (Stage 1)

For the VI pathway to be complete, there must be a source (principally volatile compounds), a potential pathway involving an impacted matrix (e.g., ground water, soil and/or soil gas), and people (i.e., receptor) (current or future) proximal to the source or pathway. In the VI receptor evaluation (Stage 1) the investigator assesses each of these components to begin the process of developing a CSM, as discussed in Section 3.1.1. Identify data gaps and prepare the preliminary approach to a VI investigation.

2.3.1 Initial Data Gathering

Once a VI investigation is triggered, implement a series of actions as stipulated in N.J.A.C. 7:26E-1.18(b). The following actions shall be completed within 60 days after the initial trigger event.

- 1) Identify all buildings and subsurface utilities (as clarified in Section 3.1.3) within 200 feet of the currently known extent of the shallow ground water contamination in excess of the Department's GWSL for volatile compounds or other triggers noted in Section 2.1;
- 2) Assess each building to determine
 - Specific use,
 - Presence of residences, schools, child care centers,
 - Existence of a basement, crawlspace, or slab-on-grade, and
 - Approximate square footage of the building footprint;
- 3) Determine the specific use, depth of the invert, diameter and construction specifications of subsurface utilities (as clarified in Section 3.1.3);
- 4) Establish the flow direction of the shallow ground water; and
- 5) Ascertain whether free product is present at each ground water sampling location.

Recognize that the 200-foot receptor evaluation criterion is utilized for the identification of buildings and subsurface utilities in all directions from the limits of the source (or trigger), not just downgradient based on the ground water flow. The investigator should make a reasonable effort to ascertain the building information within the timeframe allowed. In addition, the VI receptor evaluation should be updated each time there is further expansion to the limits of the contamination or new triggers. Thus, as new ground water data reveal the extent of the plume, additional information on buildings and subsurface utilities should be obtained (based on the 200-foot receptor evaluation criterion).

In those instances where the extent of the ground water plume has been adequately defined in accordance with N.J.A.C. 7:26E, the investigator may utilize a variance (N.J.A.C. 7:26E-1.7) of the 200 foot receptor evaluation criterion to be consistent with constituent specific critical distance criteria.

The gathering of these data will assist in developing a site-specific CSM. Based on this information, the investigator can identify data gaps and develop an investigative approach that assesses the VI pathway and potential human exposure.

2.3.2 Building and Structures

The potential for VI to impact people occupying a building and/or structure overlying or proximal to subsurface volatile contamination should be evaluated as presented in this technical guidance. While the term "building" is used throughout this document, an evaluation of the VI pathway should consider both buildings and structures, as described below, in the evaluation of the pathway.

A building is defined as an enclosed construction over a plot of land, having a roof, door(s) and usually window(s) that is or can be occupied by people and utilized for a wide variety of activities that may include, but are not limited to, residential, commercial, retail, and/or industrial uses. Examples of a building include a single family home, an apartment complex or a commercial/industrial facility, such as a strip mall or an industrial warehouse.

A structure, for the purpose of this guidance, includes a smaller construction that has limited access capability with minimal exposure potential to those individuals that may enter the structure for a much shorter period of time. Examples of a structure include a shed, small pump house or utility vault.

The investigator should use professional judgment in determining the investigative approach and need for mitigation when a reduced exposure potential is present in a building and/or structure. While unoccupied buildings or structures may present minimal exposure potential at the current time, future change in use must be considered and addressed as outlined in this technical guidance. Buildings on piers or with open air parking beneath occupied floors present a lower risk of VI, but the investigator should consider the potential of VI in higher floors via preferential pathways, such as elevator shafts or stairwells.

2.4 VI Investigation (Stage 2)

The VI Investigation stage involves the evaluation of the VI pathway through an investigative strategy as required in N.J.A.C. 7:26E-1.18(c-h). The initial round of the VI investigation shall be completed within 150 days [N.J.A.C. 7:26E-1.18(c)] after determining that a VI trigger exist.

If the current results reveal an exceedance of the Department's VI screening levels (or one of the additional factors is triggered), a VI investigation shall be developed and implemented based on the information gathered during the VI receptor evaluation phase and the site-specific CSM. Alternately, the investigator may consider the option of implementing mitigation as a proactive approach.

The Department recognizes that events often beyond the control of the investigator (e.g., obtaining access, seasonal restrictions) may necessitate a request for an extension of the regulatory timeframes.

2.4.1 Investigative Approach

The Department recommends investigating ground water (in most circumstances) as the first medium for the VI pathway (Stage 2A). Consult Section 3.2, *Ground Water Investigation and Sampling*, to ensure that the ground water data are both representative and valid for investigating the VI pathway. Depending on the site-specific CSM, the investigator may elect to conduct soil gas and/or IA sampling prior to initiating a ground water investigation.

In cases where soil contamination in the unsaturated zone represents a potential source of VI and triggers an investigation, the use of ground water data and the GWSL alone are not appropriate. The investigator should employ soil gas, IA samples or other lines of evidence, in combination with professional judgment, to assess whether soil contamination is a source of VI.

The next stage of the VI investigation is typically the collection of soil gas samples (Stage 2B). SSSG sampling is the preferred method of collecting soil gas. It allows the investigator to quantify contaminant levels in soil gas immediately under the slab of the building. Section 3.3.1, *Sub-Slab Soil Gas Sampling*, provides information on collecting SSSG samples. For assessing undeveloped parcels, employ exterior soil gas sampling. The soil gas results from sub-slab, near

slab and exterior samples (where appropriate) shall be compared to the Department's SGSL. Exceedance of the SGSL will necessitate further evaluation of the VI pathway through the collection of IA data. Alternatively, the investigator may elect to implement mitigation to address the VI pathway.

Recognizing the difficulties associated with background contamination (among several issues), IA sampling is typically the last step during an investigation of the VI pathway (Stage 2C). IA sampling provides the most direct evidence regarding the air quality within a building. Other data (ground water, soil, soil gas) simply reflect the potential for adverse impact on IA quality based on modeling or attenuation factors, and not the actual exposure. Thus, the Department recommends the collection of IA samples at this stage of the investigation. Refer to Section 3.5 for more information on IA sampling. All IA samples (including crawl space air samples) shall be compared to Department's IASL. After properly considering other lines of evidence (e.g., background sources), an IA sample that exceeds the IASL may require mitigation to eliminate the pathway (Stage 3).

2.4.2 Iterative Nature of VI Investigations

The initial round of the VI investigation shall be completed within 150 days [N.J.A.C. 7:26E-1.18(c)] after determining the need to conduct the investigation. As part of the initial round, the investigator shall, pursuant to N.J.A.C. 7:26E-1.18(d):

- Notify the Department 7 days prior to conducting the VI investigation (using the Potable Well/Indoor Air Sampling Notification Form at <http://nj.gov/dep/srp/srra/forms/>);
- Conduct the VI investigation;
- Evaluate the results;
- Submit all IA results and full laboratory data deliverables to the Department and IA data summary tables to the NJDHSS (within 14 days after receipt of the analytical data package from the laboratory – either hard copy or electronically); and
- Provide the results to each property owner/tenant and a copy to the Department (within 14 days of receipt of the analytical data package from the laboratory – either hard copy or electronically).

Concurrent with the VI investigation, delineation of the ground water contamination should be implemented. If the VI trigger is not ground water contamination (e.g., soil or soil gas contamination, vapor cloud), identify and properly delineate the source. Consequently, the process of identifying buildings and subsurface utilities, conducting additional rounds of VI investigation, evaluating the sampling data and reporting the results is repeated.

This is the iterative nature of investigating the VI pathway. The 150 day timeframe to initiate a VI investigation commences again with the discovery of additional buildings or undeveloped land that warrants investigation, often overlapping with the previous round. Due to this iterative process, the investigation may require additional rounds of sampling such that the VI study may not be completed in the prescribed timeframe.

2.4.3 Critical Distance Criteria

The Department recommends a VI investigation where buildings are within 100 feet horizontally or vertically of free product or shallow ground water contamination in excess of the GWSL. Under a future use scenario, additional investigation may be appropriate for undeveloped parcels using the same criterion. If the depth to the shallowest ground water exceeds 100 feet, a VI investigation is not required unless vertical preferential pathways exist and the CSM indicates there is a potential VI risk.

The 100-foot critical distance criterion for investigating the VI pathway does not consider the aerobic biodegradation of petroleum hydrocarbons (PHC), particularly the compounds associated with gasoline (e.g., benzene, toluene, ethylbenzene and xylenes – BTEX). Depending on the site conditions, the criterion may be too conservative for PHCs. Therefore, the Department utilizes a 30-foot critical distance criterion (both horizontal and vertical) for PHC-related ground water contamination. Refer to Chapter 5 for a clarification on PHCs, especially No. 2 and diesel fuels, and exclusion criteria for gasoline-related discharges.

The 100-foot critical distance criterion shall be used for all free product, PHC-related or otherwise (N.J.A.C. 7:26E-1.18(a)).

It should be understood that the critical distance criteria are applied from the edge of the ground water plume based on linear interpolation (not a contaminated monitoring well) when determining which buildings should be investigated. It is unacceptable to assume the VI pathway is incomplete based on the collection of a ground water sample at a distance less than the prescribed criterion. The critical distance criteria are based on the migration of vapors through the vadose zone and are irrespective of the presence of contaminated ground water within that distance. The criteria are also applied exclusively to the horizontal or vertical distance from the contaminated ground water plume.

2.4.4 Data Usability

One of the decision points in the screening process is to determine whether the analytical data are valid and representative. This is an all-inclusive phrase designed to address a variety of issues dealing with the usability of the analytical data. Relevant questions of this step include the following:

- Was the sampling approach appropriate for the investigation of the VI pathway (including seasonal variability for IA samples) and accurately followed by the investigator?
- Were the samples properly collected - consistent with the most recent version of the NJDEP Field Sampling Procedures Manual (FSPM) (NJDEP 2005a) and this guidance?
- Is the investigator confident that the sampling equipment was not moved or otherwise tampered with?
- Were the data properly reviewed and determined to be acceptable?
- Was consideration given to potential background contamination?
- Were all other issues that might impact on the data's usability addressed appropriately?

Each of the above questions should be answered affirmatively in order to proceed along the flow path. Any negative responses may indicate false positive or negative bias in the data acquisition that may require the collection of additional analytical data.

Based on the concept of multiple lines of evidence, other types of data (e.g., field analytical, meteorological, observational) can be utilized in the assessment of the VI pathway. Consult Chapter 4 for additional information.

2.4.5 Site-Specific Options

At any point during Stage 2 (after a VI investigation has been triggered), the investigator can elect to utilize site-specific screening options as part of the VI investigation. The use of site-specific screening levels, modeling or other alternative approaches will likely trigger a Departmental review or inspection. Therefore, it is recommended that a technical consultation (http://www.nj.gov/dep/srp/srra/technical_consultation/) be obtained with the Department.

While the Table 1 GWSL are based on the presence of sandy soils, the Department has developed GWSL for Alternate Soil Textures, as presented in Table 3 of the Department's VI website (<http://www.nj.gov/dep/srp/guidance/vaporintrusion/>), utilizing loamy sand, sandy loam and loam soil that result in less conservative screening levels. Laboratory soil grain size analysis, as described below, should be documented to justify the use of the GWSL for Alternate Soil Textures at a site.

Laboratory soil grain size analysis should demonstrate at least 75% of the soil vertical profile is as fine-grained as the soil texture selected for use of the Table 3 screening levels. If this criterion is not met, use the coarsest soil texture.

Base the acceptance of an alternate soil texture on soil texture analysis. To establish soil texture, collect soil cores using a Shelby Tube, direct push sampler, or split spoon. One representative boring within 10 feet of the building will be sufficient for most single-family homes with additional borings necessary for larger buildings. Collect the soil cores/samples continuously (every two or four feet depending on the length of the sampling device) from the base of the slab depth to the surface of the static water level. Collect a grain size analysis on the cores/samples. A variety of methods exist to determine grain size of a given soil sample. The Department accepts all of the following techniques: sieve analysis for the sand and gravel portions of a given sample with pipette or hydrometer measurements of the silt and clay fractions, rapid sediment analyzers, hydrometer method, and electro-resistance multichannel particle size analyzers.

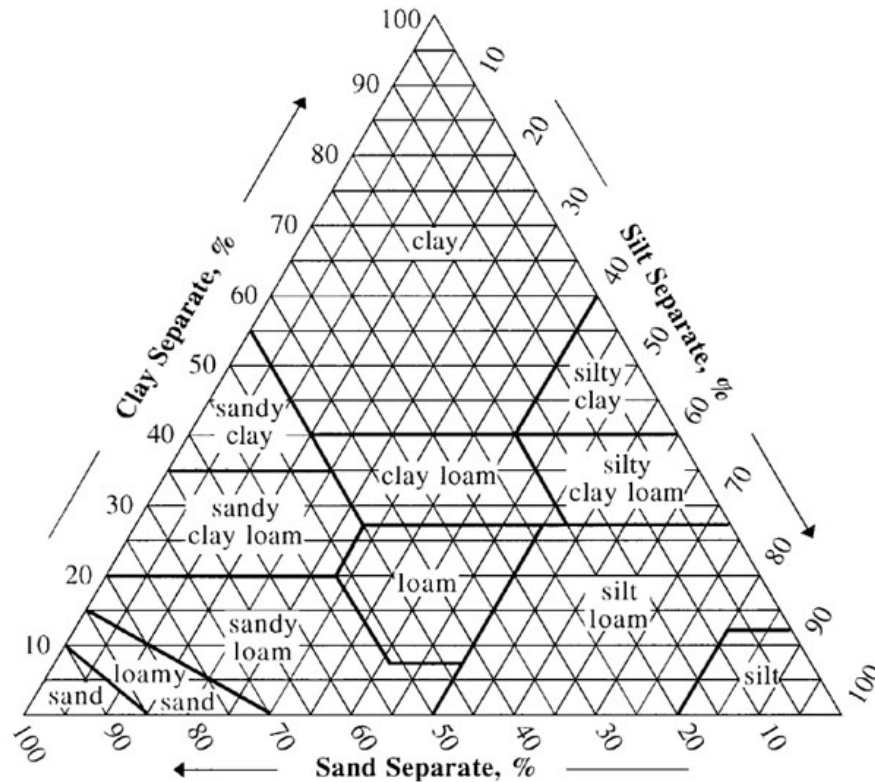


Figure 2-1
Soil Classification System (USDA)

The percentages of sand, silt and clay determined by the chosen analysis techniques are then compared to the United States Department of Agriculture (USDA) Soil Texture Triangle to determine the soil texture classification (Figure 2-1). Under the USDA Soil Texture Triangle, sands are considered particles between 0.05 mm and 2 mm in size, silts are between 0.05 mm and 0.002 mm and clays are less than 0.002 mm in size.

The investigator should properly document the building-specific soil texture in the appropriate reporting document.

Additional site-specific options available to the investigator (based on professional judgment) are as follows:

- Utilization of alternative soil gas sampling procedures (flux chambers, continuous monitoring, vertical depth profiling);
- Assessment of biodegradation for PHCs through data collection (O₂ & CO₂ levels in subsurface soils, depth to ground water table) or modeling; and
- Implementation of other appropriate site-specific screening options using a MLE approach.

2.5 Mitigation (Stage 3)

Once the VI investigation is complete, a selection of the appropriate mitigation shall be made, if applicable (N.J.A.C. 7:26E-1.18(f)). Consult Chapter 6, *Vapor Intrusion Mitigation*, for technical guidance on the applicable mitigation alternatives.

2.5.1 Vapor Concern

When the results from an IA sample exceed the Department's IASL (but is equal to or less than the Department's RALs) and it is reasonable to conclude that the VI pathway is complete, a VC is triggered. The investigator shall notify the Department within 14 days of receipt of the data package (N.J.A.C. 7:26E-1.18(f)) using the VC Response Action form available at <http://nj.gov/dep/srp/srra/forms/>. This action will trigger the assignment of a Department Case Manager. After this point, the investigator should communicate with the Case Manager on all future actions.

N.J.A.C. 7:26E-1.18(f) requires the submission of a VC mitigation plan to the Department within 60 days after receipt of the analytical data to address the exposure. The VC Mitigation Plan shall be initiated within 120 days after receipt of the analytical results. Finally, a VC mitigation response action report shall be submitted to the Department within 180 days after receipt of the analytical data. Refer to Section 6.1.2.3 for additional information on the components of the VC mitigation plan and Section 6.4.4 for the VC mitigation response action report.

2.5.2 Vapor Intrusion Immediate Environmental Concern

When the results from an IA sample exceed the Department's RALs and it is reasonable to conclude that the VI pathway is complete, a VI IEC is triggered (N.J.A.C. 7:26E-1.14). The investigator shall immediately notify the Department of the IEC. As with the VC, a Department Case Manager will be assigned to ensure that the exposure is eliminated in a timely manner.

Within 14 days after the VI IEC identification, the investigator shall:

- Notify the building's occupants/owner about the contamination;
- Implement an interim response action (IRA) to reduce contaminant levels;
- Submit an IEC response action form, a VI spreadsheet, all analytical data packages, and an IEC map to the Department; and,
- Submit all IA analytical results to the NJDHSS.

The investigator shall implement an engineered system response action (ESRA) to mitigate the VI IEC within 60 days after triggering the IEC (N.J.A.C. 7:26E-1.14). In addition, a receptor delineation investigation of potential impacts to other nearby buildings (including sampling) shall be conducted concurrently with the implementation of the ESRA (60-day timeframe). An IEC ESRA report shall be submitted to the Department within 120 days after the IEC is first identified.

For more information, please refer to the Department's Immediate Environmental Concern Technical Guidance (<http://www.nj.gov/dep/srp/guidance/>).

2.5.3 Institutional Controls and Future Use

Establish institutional controls as part of any ground water remedial action and resulting maintenance and monitoring requirements to address current/future use of the subject property. Depending on the level of contamination present and other site-specific factors, current (and potentially future) inhabited buildings or environmental media may be monitored to assess any VI risk. Building construction can incorporate designs to address the VI pathway. Engineering controls may be appropriate based on the results of the VI investigation, current/future land use and site conditions (see Chapter 6).

2.6 Operation, Maintenance and Monitoring (Stage 4)

Based on the type of mitigation selected, monitoring should be implemented (as discussed in Section 6.5). Monitoring may or may not involve the collection of analytical samples. For example, monitoring of subsurface depressurization systems may be limited to periodic readings of the static pressure and flow measurements for each system suction point and fan inlet.

Maintenance and review of current operations of the mitigation is an essential part of the process. Periodic inspections of the system or engineering and institutional controls ensure that the VI pathway remains incomplete. Refer to Section 6.4, *Post-Mitigation Activities*, for additional information.

2.7 Termination (Stage 5)

Finally, the decision to terminate the mitigation is dependent upon the remediation of the VI source to the point where the VI pathway is not complete (Stage 5). Make a determination on system termination through the collection of IA and SSSG samples (as discussed in Section 6.6).

3.0 INVESTIGATIVE APPROACHES

3.1 Conducting a Vapor Intrusion Investigation

VI investigations shall be conducted consistent with the Technical Rules and the specific investigative provisions contained in N.J.A.C. 7:26E-1.18. When submitting the results of the sampling event, the investigator shall provide a written technical rationale for not applying any provision from this technical guidance (N.J.S.A. 58:10C-14c(4)).

3.1.1 Conceptual Site Model

The CSM is the typical starting point for the preparation of a VI investigative approach. The Department recommends early development of a CSM that can be used to plan, scope, and communicate the development of a VI investigation and any needed mitigation.

While the CSM can greatly assist in evaluating results of an investigation, it does not have to be a written document or be submitted to the Department.

The CSM allows the investigator to better understand the source of contaminants, the pathways traveled, the people potentially or actually exposed to contaminants, and the location of each of these in relation to the other. Buildings with known sensitive populations (e.g., residents, schools, childcare centers) shall be identified early through the VI receptor evaluation (N.J.A.C. 7:26E-1.18) and prioritized for VI investigation.

One of the goals of the VI investigation is to test or refine the CSM. Thus, the data generated from the investigation should support the basic understanding as laid out in the CSM. If not, either the CSM needs to be modified or the data are deficient.

To assist the investigator in preparing this vital component, utilize the *ITRC Conceptual Site Model Checklist* found in Appendix C. In addition, the investigator is directed to consult the Department's Conceptual Site Model Technical Guidance (<http://www.nj.gov/dep/srp/guidance/>).

3.1.2 Investigative Tools

There are a number of investigative methods for assessing the VI pathway, principally involving ground water, soil gas and IA sample collection. Other tools unrelated to chemical analysis can also be employed as part of an overall MLE approach to assessing the VI pathway.

3.1.2.1 Ground Water Sampling

In most situations, ground water will be the first medium to be evaluated for the VI pathway. A remedial investigation of ground water requires (N.J.A.C. 7:26E-4.1) the characterization and delineation of ground water contamination. The extent of the ground water plume, as well as the concentrations of the contaminants, allow for an initial assessment of the VI pathway. In most cases, exceedance of the NJDEP GWSL necessitates further evaluation and probably more field investigation.

Follow Section 3.2 below for VI ground water investigations. Quality assurance (QA) issues (e.g., QA samples, analytical methods, and deliverables) for ground water sampling should be consistent with the most recent version of the Department's FSPM (NJDEP 2005a).

As a general rule, the collection of SSSG or IA samples is not recommended prior to a basic assessment of the site hydrogeology, including soil profile, geologic stratigraphy, ground water depth, flow direction and contaminant concentrations. False assumptions may be reached on the VI pathway based on an incomplete picture of the site hydrogeology (as defined in the CSM). It should be understood, though, that the potential for an IEC may necessitate the collection of SSSG and/or IA samples prior to acquisition of sufficient ground water data due to the urgency of the potential human exposure, particularly to sensitive populations. The presence, quantity and location of non-aqueous phase liquid (NAPL) in the vadose zone close to buildings may also indicate that the collection of soil gas and/or IA samples should precede collection of ground water analytical data.

3.1.2.2 Soil Gas Sampling

An exceedance of the Department's GWSL necessitates further investigation of the VI pathway. In most cases, soil gas sampling is the most logical next step in the VI investigative process.

This technical guidance defines soil gas results based on the location of the sample: sub-slab (below the foundation slab), near slab (within 10 feet horizontally of the foundation) or exterior (outside of the 10-foot perimeter of the foundation). In addition, data can be obtained from passive soil gas sampling procedures as a supplement to the traditional active soil gas collection.

The investigator should collect SSSG samples as the principal investigative tool for soil gas sampling to evaluate the VI pathway. Near slab soil gas sampling is an acceptable alternative when it is verified that obtaining sub-slab samples is not possible. (Refer to Section 3.3.2 for additional information on *Alternative Soil Gas Sampling*). Utilize the results of near slab soil gas sampling as a line of evidence to assess whether the VI pathway is currently complete for a particular building.

Sometimes, it is necessary to investigate the subsurface soil gas under buildings with existing sub-slab depressurization systems (SSDS) designed to address either radon or VI. In these cases, turn off the SSDS fan (if present) and cap the vent pipe a minimum of 48 hours in advance of the SSSG sample collection. Locate the sub-slab sampling point(s) away from existing SSDS suction points, floor drains, sumps and any other openings in the slab, if possible (O'Brien & Gere, 2009). When the occupants are unwilling to allow the SSDS to be shut off, an alternative could involve conducting a communication tests across the entire slab in combination with IA sample(s). Refer to Section 6.6 if the SSSG sampling is being proposed as part of system termination.

SSSG samples may also be more appropriate when obtaining representative ground water data is not possible or is impractical.

Soil gas sampling approaches should take into account the different exposure scenarios (e.g., child care centers, offices) that exist within the building and any sensitive populations that may be exposed to the contaminated vapors. In addition, the presence of subsurface structures (sumps, dry wells, underground fuel sources, etc.), can exacerbate the VI pathway and possibly degrade IA quality in one portion of the building and not another.

In situations where contaminated unsaturated soils or vapor clouds are the primary potential source, sub-slab or near slab soil gas samples are the principal mechanism for investigating the VI pathway (other than IA samples).

Underground storage tank sites or sites where chlorinated solvents are used in buildings or facilities at the surface (e.g., dry cleaners, vapor degreasers) may have contamination in the vadose zone due solely to vapor releases. In these cases, soil and ground water data may not identify the VI source. Soil gas data are the preferable investigative tools where vapor leaks (or vapor clouds) are suspected.

Sites that involve contaminated unsaturated soils or vapor releases are two examples where a vertical profile of soil gas concentrations may assist in the investigation. Vertical profiling can better clarify the source(s) of VI by evaluating the distribution of chemical concentrations over a defined depth. If a ground water plume under a building is the suspected source, soil gas concentrations should increase as the depth of the sample collection increases. Aberrations from this general assumption may suggest an alternative source, such as preferential pathways, vapor clouds, surface spills or vadose zone soil contamination, provided the data are not affected by bias or variability.

The investigator should also recognize circumstances where SSSG samples may not be a good indicator of VI. For example, soil contamination in the vadose zone may generate vapors that migrate into a building by way of subsurface utilities typically at a depth of 3-6 feet below the surface. Under this scenario, soil gas concentrations under a basement slab (8-10 feet below the surface) may not detect a VI concern.

Undeveloped parcels without existing buildings present a unique situation for the investigation of the VI pathway. The collection of SSSG or IA samples is not possible without a building on the parcel. In this case, an MLE approach can be employed to assess the potential for VI under a future use scenario and potentially lead to a no further action determination. The lines of evidence may include:

- delineation of the ground water plume;
- analysis of soil gas samples just above the water table using a grid sampling approach and biased towards the highest concentrations within the ground water plume;
- utilization of J&E model with NJDEP-specific input parameters;
- implementation of pneumatic testing (soil permeability); and
- assessment of soil stratigraphy and /or vertical profiling of soil gas concentrations.

While not specifically identified by the Technical Rules, the investigator should consider undeveloped parcels within the prescribed critical distance criteria for a VI investigation.

A VI investigation for undeveloped land will not be necessary if the landowner is willing to voluntarily accept an institutional control that stipulates any future development must consider the VI pathway. This can be accomplished by incorporating the presumptive remedy into the design of the building(s) or conduct a VI investigation at that time. In addition, these provisions should be included in the monitoring, maintenance and evaluation (MME) plan of the ground water CEA.

When in situations where the exterior soil gas investigation is being conducted to assess a future use scenario at an undeveloped parcel, the results should be compared to the Department's SGSL.

Exterior soil gas samples can also be employed as a screening tool to assist with the delineation of the ground water plume (but not the direct assessment of the VI pathway). However, support the final plume delineation by the collection of confirmatory ground water samples at strategic locations. In these cases, a mobile lab employing USEPA Method 8260B (or similar methods) may expedite the investigation and allow the flexibility to modify the sampling strategy in the field (Triad approach).

Lastly, passive soil gas sampling may be applicable to the preliminary delineation of the ground water plume or vadose zone sources. Support the final plume delineation by the collection of confirmatory ground water samples at strategic locations. Passive soil gas results are not acceptable as the only line of analytical evidence in assessing the VI pathway.

3.1.2.3 *Indoor Air Sampling*

IA sampling is generally the last investigative step in the evaluation of the VI pathway. Due to legitimate concerns over background sources, IA results provide a unique challenge to investigators (refer to Chapter 4, *Multiple Lines of Evidence and Data Evaluation*, for additional information). The Department recommends the collection of SSSG and ambient air samples in conjunction with IA sampling events to assist in the evaluation of background sources.

IA sampling is often necessary to properly assess whether the VI pathway is complete in several situations, such as:

- exceedance of the SGSL;
- shallow ground water table that prevents the collection of soil gas data;
- site-specific approach is utilized which requires supplemental data in support of the conclusions;
- preferential pathways exist that may negate or limit the usefulness of ground water or soil gas data;
- presence of contaminated ground water in a sump;
- IECs that require a more immediate response;
- volatile chemicals in bedrock near or at the surface (eliminates the applicability of J&E);
or
- other site-specific factors.

Because IA sample locations are a critical issue in the ultimate assessment of the data, the VI investigation should clearly identify the criteria that will be employed in selecting sample location. Refer to *Conducting a Building Walkthrough and Survey* (Section 3.4) for additional technical guidance on this phase of the investigation.

An ambient air sample provides background concentrations outside of the building being investigated at the time of the IA sampling event. When using USEPA Method TO-15 (USEPA 1999), the canister used for the ambient air sample should be randomly selected from the canisters sent by the laboratory and placed outside of a building or group of buildings that are being sampled. The ambient air sample should have the same sample collection time and be analyzed in the same manner as the interior sample to the extent practicable. The investigator should clearly designate sample location and the site conditions at the time of sampling. The investigator also should be aware of the weather conditions during the sampling event. Thus, the canisters should be placed in a secure outside location. Take ambient air samples at breathing zone height (if possible) and in close proximity to a residential building. For non-residential buildings, the investigator may elect to collect the ambient air sample near representative heating, ventilation and air conditioning (HVAC) intake locations (i.e., on the roof).

3.1.2.4 *Soil Sampling*

At this time, the Department has not developed VI screening levels for soil. Compare soil gas and IA results to the applicable screening levels to assess the vapor potential from contaminated soils. Otherwise, make a site-specific determination as to whether further investigation of the VI pathway is warranted for contaminated soils. The investigator should note that high soil concentrations may be useful as an indicator of the depth and/or extent of the vadose zone sources. Soil samples for VOCs have a potential for negative bias due to volatilization losses and generally higher reporting limits (RL) compared to soil gas samples.

3.1.2.5 *Other Investigative Tools*

In addition to the typical sample collection for chemical analysis, other investigative tools may assist in the assessment of the VI pathway. Refer to the ITRC [Vapor Intrusion Pathway: A Practical Guideline](http://www.itrcweb.org/guidancedocument.asp?TID=49) (ITRC 2007) (<http://www.itrcweb.org/guidancedocument.asp?TID=49>) for detailed information on the various investigative tools available.

Investigators can evaluate soil properties by visually inspecting soil cores, determining soil texture, or ascertaining porosity and moisture content.

Soil pump tests can be conducted to analyze pneumatic properties or correlate the changing concentration verses volume purged.

Weather conditions can often influence advective flow of soil gas into a building. Thus, monitoring barometric and differential pressure, as well as wind speed and precipitation, can be recorded to document daily or seasonal trends.

Building-specific parameters, including pressure testing and ventilation rate determinations, can serve to supplement Test and Balance Reports (if available) and support potential mitigation measures involving the manipulation of building pressure.

The collection of vertical profiles of oxygen and carbon dioxide readings in soil gas samples can be utilized to substantiate that biodegradation is occurring, particularly for PHCs in the subsurface.

Finally, modeling results can be used as another line of evidence in assessing the VI pathway. Employing modeling will likely trigger a review or inspection by the Department. Therefore, it is recommended that the investigator utilize the Department's Technical Consultation Process to obtain regulatory input. Refer to Section 2.4.5 for additional information.

As the science of VI advances, additional technologies will be developed to assess the pathway. With proper documentation, these new technologies can be employed.

3.1.3 Preferential Pathways

Due to the nature of vapor migration, VI investigations shall assess the presence of preferential pathways pursuant to N.J.A.C. 7:26E-1.18 (b), whether natural (e.g., shallow rock or vertically fractured soil) or anthropogenic (e.g., buried utilities).

As part of the VI receptor evaluation (Stage 1), the investigator shall evaluate the possibility of interconnections between a source and a building through subsurface utilities. Specifically, the use, the depth of the invert, the diameter of the conduit, and the construction specifications of utility lines shall be determined. Identify natural features that may act as preferential pathways.

In general, typical subsurface utilities (water, gas, sewer, cable, etc.), as they relate to N.J.A.C. 7:26E-1.18(b), do not have to be identified for single-family residential buildings and other similarly sized buildings as part of the VI receptor evaluation. An exception to this provision is when these typical subsurface utilities run through or are relatively close to source materials (e.g., free product, soil contamination). However, any lateral lines servicing large residential buildings or units, commercial, retail or industrial buildings, or main lines servicing groups of buildings (residential or otherwise) shall be identified, as well as utility vaults or other underground structures.

Larger lines and utility corridors for main lines constructed using bedding material and fill are more likely to act as significant preferential pathways for vapors, contaminated ground water, or NAPL migration and may be important in developing an accurate CSM. Utility vaults and underground structures that can be associated with larger utilities may also be subject to VI and in extreme cases can pose a threat of explosion or an oxygen deficient atmosphere.

Determining construction specifications of subsurface utilities, as required in N.J.A.C. 7:26E-1.18(b)3, can be limited to characteristics with the potential for influencing contaminant migration, such as the type and extent of any bedding or fill materials used.

It may be necessary for the investigator to determine whether any utilities may be acting as conduits for vapor migration, either along the utility's backfill or within the utility itself. This determination should include, but not be limited to, visual inspection and the use of field screening instruments (with appropriate detection limits based on the SGSL). The State of Wisconsin guidance document (WDNR, 2000) provides additional information on assessing utility corridors as part of a VI investigation.

3.1.4 Landfills and Methane Gas

The Technical Rules currently require performing a VI investigation when a landfill is located on or adjacent to a site. The presence of methane-generating conditions that may cause an explosion will also trigger a VI investigation. However, the investigator may request a variance from the landfill trigger (N.J.A.C. 7:26E-1.18(a)4.ii) if no other triggers exist at the site that require a VI investigation. It is still necessary to identify any landfills on or adjacent to a site when a VI investigation is triggered. Landfills and the gas generated from them can greatly influence the CSM and the investigative approach (as discussed below).

A landfill is defined in N.J.A.C. 7:26E-1.8 as a solid waste facility, at which solid waste is deposited on or into the land as fill for the purpose of permanent disposal or storage for a period of time exceeding six months, except that the term sanitary landfill shall not include any waste facility approved for disposal of hazardous waste regulated pursuant to N.J.A.C. 7:26G. A facility is a sanitary landfill regardless of when solid waste was deposited or whether the facility was properly registered, permitted, approved or otherwise authorized to conduct such activity, by the Department or other State agency. By this definition, a landfill also includes an area of concern (AOC) where waste was dumped on the ground surface or buried below the ground surface. This definition also includes AOCs that were not designed or permitted to function as a landfill for the disposal of solid waste.

While the concern for the migration of naturally produced or anthropogenic methane and the potential for the concentration of methane to exceed the lower explosion limit in a building are similar, the investigation of these issues requires the consideration of site-specific conditions.

3.1.4.1 *Methane*

Methane is non-toxic and is therefore not a long-term human health risk due to exposure. It is a colorless, odorless hydrocarbon combustible at concentrations of 5-15% by volume in air. Methane may be generated under natural conditions or from an anthropogenic source. Organic-rich soils, sediments or methane associated with natural petroleum reserves are examples of natural methane-producing conditions. In New Jersey, fill over marine clays may be a typical source. Anthropogenic sources include landfills and agricultural wastes.

3.1.4.2 *Landfill Gases*

Landfill gas (LFG) is the natural by-product of the anaerobic decomposition of biodegradable material that is placed in landfills. The composition of LFG produced under anaerobic conditions is typically in the range of 45-60% methane and 40-60% carbon dioxide. Additional components of LFG include trace amounts of ammonia, hydrogen sulfide and other non-methane organic

compounds including VOCs. Nearly 30 organic hazardous air pollutants have been identified in LFG including, but not limited to, benzene, toluene, ethylbenzene, vinyl chloride, chloroform, carbon tetrachloride and trichloroethene (TCE). A useful source of information on this subject is the USEPA publication, Guidance for Evaluating Landfill Gas Emissions for Closed or Abandoned Facilities (USEPA, 2005).

Because of its combustible nature, methane is the primary product of interest at landfills for VI investigations along with the volatile compounds that are carried along in the LFG plume. It should be noted that New Jersey Solid Waste regulations (N.J.A.C. 7:26-2A7(f)) require active landfill gas (LFG) collection and venting, if 25% of the lower explosive limit (LEL) is detected at the perimeter of the property, to prevent offsite migration and control the accumulation of any methane gas at any concentration in any building.

3.1.4.3 *Landfill Gas Production and Flow*

The rate and volume of LFG production depends upon the characteristics of the waste material and the environmental factors. They include the following:

- Waste composition - The greater the amount of biodegradable organic materials present in the waste (typically from municipal waste), the more LFG is produced by bacteria during decomposition. In addition, the more industrial waste that is disposed in the landfill, the higher the levels of non-methane organic compounds that will be produced through volatilization and chemical reactions.
- Age of the waste – Generally waste buried for less than 10 years produces more LFG than older waste. Peak gas production is between 5-7 years after the waste is buried but can continue up to 50 years after waste placement.
- Presence of oxygen – Methane is produced in anaerobic regions of the landfill and can be consumed in aerobic regions.
- Moisture content – The presence of moisture increases the gas production because it supports and enhances bacterial decomposition. Moisture may also promote chemical reactions that produce LFG.
- Temperature – As temperature increases the rate of bacterial activity will increase, which increases gas production. Increasing temperatures also promote volatilization and increase the rate of chemical reactions.

Migration of LFG may occur because of diffusion or advection. Gas flow by advection occurs when a pressure gradient exists. Thus, gas flow is in the direction of decreasing pressure - from high pressure to low pressure. When LFG concentrations are higher in a landfill than the surrounding area, LFG will tend to move out of the landfill to the surrounding area with a lower gas concentration. Gas flow due to diffusion is in the direction which the concentration decreases.

Factors that influence the flow of LFG in the subsurface include the following:

- Landfill cap – If the landfill has a cap consisting of a liner or silts and clays that are impermeable to gas flow, LFG gas will tend to migrate laterally.

- Landfill liners – If the landfill has an impermeable liner system, LFG will not migrate into the surrounding subsurface area by advection.
- Ground water levels – Gas movement is influenced by the movement of the ground water table. As the ground water table rises, it forces the LFG upward.
- Barometric pressure – The difference in the soil gas pressure and the barometric pressure will guide the LFG to move laterally or vertically, depending upon the pressure gradient.
- Preferential pathways – Pathways for the movement of LFG can be either natural or anthropogenic. The geology provides natural pathways such as sand or gravel zones, fractured bedrock and old stream channels. Anthropogenic pathways include buried utilities, drains, trenches and tunnels.
- Seasonal Variations – The time of year (winter, summer) will cause variations in lateral LFG movement due to saturated soils from precipitation acting as a cap for vertical LFG migration and increased LFG production in the late summer and early fall season potentially increasing horizontal distance for LFG migration.

It is often difficult to predict the specific patterns and directions of LFG movement due to the many variables for gas flow and generation. In most cases LFG can migrate up to 1,000 feet (or more) in the subsurface from the footprint of the refuse (landfill source).

3.1.4.4 *Landfill Building Requirements*

On the landfill, a VI investigation should not be necessary and would be technically challenging and difficult to obtain accurate data to assess potential future exposures, so remedial actions for landfills should include mitigation of the VI and gas migration pathways for methane and volatile compounds as part of the cap or building design. If buildings currently exist on a landfill that are or could be occupied, then conduct a VI investigation that consists of sub-slab and IA sampling for volatile compounds and methane/explosive gas.

On-site buildings within the sanitary landfill properties should be designed and constructed in accordance with specification in the regulations, or in accordance with an equivalent design which will prevent gas migration into the building (N.J.A.C 7:26-2A.7(f)14).

An alternative design to N.J.A.C 7:26-2A.7(f)14 for the construction of on-site buildings within the sanitary landfill properties that are constructed on piles can use an open space (crawl space) between the final ground surface elevation and the building floor to allow for the installation and operation of an active methane gas venting system. The active gas venting system shall be capable of preventing the accumulation of gas at or greater than 25% LEL in the crawlspace. The venting system must also eliminate the pathway for volatile compounds. The requirements in N.J.A.C 7:26-2A.7(f)14vi and vii shall be complied with at all times.

Consult information in 40 CFR Part 258 as an additional reference.

3.1.4.5 *Methane Investigations and Analytical Methods*

In general, the landfill proper (footprint of the refuse) does not necessitate the implementation of a VI investigation. New Jersey Solid Waste regulations specifically address landfill requirements

regarding investigation of LFG and building-specific mitigation provisions. Sites near or adjacent to landfills, however, do warrant investigation for LFG and VI.

When methane may likely be present (see Section 3.1.4.1), the investigator should initially assess the buildings identified through the receptor evaluation for fire and explosion hazards. The characterization should focus on below grade floors, ground level floors (when no basement present), crawl spaces, sumps, utility penetrations, utility vaults, and enclosed spaces. If explosive conditions are present, immediate notification of emergency responders is required followed by Department notification in accordance with the Technical Rules (N.J.A.C. 7:26E-1.18(c)2vi).

Once the investigator determines that an explosive condition does not currently exist at the building, an evaluation of VI for volatile compounds and non-emergency methane concentrations should follow. The absence of methane does not eliminate the possibility of volatile compounds in a building.

For sites located on or near a landfill (excluding the footprint of the refuse), there are several methods to assessing the impact from the landfill.

1. Probes can be installed at several levels in the vadose zone between the site and the landfill to allow for measurements of subsurface pressure and methane concentrations to evaluate the attenuation and migration potential of methane in the soil column. Install the deepest probe at the approximate depth of the landfill refuse, or just above the water table. The investigator uses professional judgment to determine the number of vertical profiles. While samples can be collected in summa canisters for laboratory analysis, a field instrument capable of directly measuring methane (e.g., landfill gas analyzer, combustible gas meter, flame ionization detector (FID)) can be used. Evaluate preferential pathways that may serve as migration routes to buildings. Based on the results, the investigator can determine if LFG is reaching the site. If the data suggest that the LFG is reaching the site, incorporate method #3 (below) into the VI investigation.
2. Obtain initial information regarding LFG migration from the landfill owner/operators if they were required to monitor for LFG at the perimeter of the toe of the landfill (N.J.A.C. 7:26-2A.7(h)6). Information on the periodic LFG measurements should give an indication of the potential (pressure) and concentrations of LFG migrating off the landfill property. Other factors listed in Section 3.1.4.3 may assist the investigator, including the type and age of the landfill, landfill construction (e.g., cap, liner), and the presence of an active methane gas venting system. If the data suggest that the LFG is reaching the site, incorporate method #3 (below) into the VI investigation.
3. The investigator can incorporate methane analysis and sub-slab pressure readings into the traditional VI investigation process for soil gas and IA samples.

For VI investigations that have the potential for methane to be present in the subsurface from a landfill or other methanogenic environmental conditions, complete a measurement to determine the sub-slab methane concentrations and pressures.

Analytical methods for methane include:

- USEPA Method 3C (methane, carbon dioxide and oxygen);
- Methane Specific IR Gas Analyzer (Landfill Gas Meter);
- Combustible gas meter (catalytic detector-only if oxygen is above 19.5%); and
- FID w/ charcoal scrubber (only if oxygen is above 19.5%).

Complete measurements of the sub-slab pressures with a manometer capable of reading 0.001 inches of water. Collect measurements during SSSG testing from permanent or temporary soil gas probes provided the measurements are made with no building depressurization (heater, vent fans, etc.).

As noted in Section 3.1.4.3, the critical distance criteria do not necessarily reflect the distance LFG can travel from a landfill, often carrying site-related COCs. If the investigator can establish that LFG is not reaching the site, employ the standard critical distance criteria discussed in Section 2.4.3.

The investigator, however, should use method #3 above if the landfill is affecting the site. Under this scenario, the VI investigation would be implemented as provided in this technical guidance initially and allow the results of the methane and volatile analyses to dictate the necessity to employed a step-out approach beyond the standard critical distance criteria. The investigator should establish a clean zone beyond the limits of VI contamination consisting of two residential properties or 100 feet, whichever is more. A clean zone would have 0% LEL. Professional judgment utilizing the MLE approach (see Chapter 4) should guide the investigator when dealing with landfills.

Consider sources of methane in buildings (sewage systems, natural gas equipment). As previously stated, the measurement of methane from LFG may also indicate the presence of other volatile compounds in the absence of other screening conditions such as dissolved volatile compounds in ground water or volatile compounds in soil. Finally, exercise appropriate care before entering confined spaces to conduct methane screening.

3.2 Ground Water Investigation and Sampling

This section addresses the following:

1. technical guidance on saturated zone features that may affect VI sampling decisions
2. acceptable use of pre-existing ground water data
3. procedures for obtaining new ground water data to evaluate this pathway

3.2.1. Saturated Zone Features Affecting Vapor Intrusion

Many of the concepts and properties discussed below are more applicable to subsurface formations where the ground water flow regime is relatively homogeneous (e.g., unconsolidated or sedimentary formations), however, more heterogeneous flow regimes are also addressed in several discussions. Topics include the following:

- Clean Water Lens
- Depth to Saturated Zone and Stratigraphy

- Fluctuations in Depth to Saturated Zone
- Complex Hydrogeologic Settings
- Proximity to Preferential Pathways
- Potential for Contaminant Degradation

3.2.1.1 *Clean Water Lens*

If a clean water lens exists above the volatile contamination, it can act as a barrier to volatilization from deeper ground water (Rivett, 1995). This could reduce or prevent VI into overlying buildings. A clean water lens of three feet or greater may be an appropriate barrier to prevent volatilization into overlying buildings. If the clean water lens is at least three feet thick but less than 6 feet thick, perform periodic monitoring of the clean water lens thickness during seasonal low water levels (i.e., later summer to early autumn) to establish the minimum clean water thickness of three feet.

Where clean water lens is an important element of the CSM, multi-depth sampling within a well or temporary boring (i.e., vertical profiling) may be appropriate. Other acceptable methods of sampling ground water at multiple depths in the same location horizontally may be appropriate as well (see Section 3.2.3.1 below). A clean water lens immediately above a plume cannot be determined without vertical profile data or use of other acceptable multi-depth sampling approaches to document the approximate depth of the vertical transition from clean to contaminated ground water.

A clean water lens that is thicker than the annual water table fluctuation range can be a barrier to off gassing of volatiles from ground water to soil gas. If a clean water lens is thin, relative to short term, seasonal and/or longer term drops in the water level (natural or anthropogenic) it is likely that a falling water table will expose a plume to the vadose zone. Document the approximate thickness of a clean water lens to use the guidelines in Section 4.3.3 regarding whether the plume is or is not a source for VI.

3.2.1.2 *Depth to Saturated Zone and Stratigraphy*

The water table means the surface of the body of unconfined ground water where the hydrostatic pressure is equal to atmospheric pressure (<http://nj.gov/dep/srp/bust/defs.htm#wat>). The depth to the regional water table and any perched saturated zone(s) needs to be determined near buildings at risk for VI. The vertical distance between the water table and building slabs should also be determined. A “perched” water table is formed by a relatively low permeability layer that is recharged at a rate that exceeds the percolation rate through this layer. A perched water table is associated with a zone of saturation above a relatively low permeable layer, with unsaturated materials beneath it.

Use boring or test pit logs in the area of a VI investigation as follows:

- determine the soil profile (soil type and texture)
- look for stratigraphic changes or soil horizons indicative of high moisture content, a perched water table, or high organic carbon content

- evaluate characteristics of the strata immediately below and above the water table

The depth of the water table and/or first zone of saturation should be determined as follows:

- help determine ground water flow direction (with surveyed ground surface elevations)
- decide appropriate media for further investigation
- determine the depth of ground water sampling

3.2.1.3 Fluctuation in Depth to Saturated Zone

Changes in water table elevation may increase or decrease the risk of VI. The cause of the water level change and the proximity and nature of the source of the ground water contamination (e.g., age or size of source) affect the potential for VI. The water table elevation fluctuates and perched saturated zones may dry up seasonally or only exist periodically after precipitation events. If a perched saturated zone is present, extensive enough, and clean, it could prevent migration of vapors through it, or around it, from underlying contaminated ground water.

Significant fluctuations in the water table elevation also affect the predictability of VI using analytical modeling approaches where ground water quality is the source input parameter. Proper ground water sampling design may overcome this potential limitation.

3.2.1.4 Complex Hydrogeologic Settings

Heterogeneity in subsurface media could influence whether volatiles in saturated zones become a source for VI. Consider information on the locations and depths of near surface features such as clay, till or gravel layers/lenses and depth to bedrock. Such features should be taken into account when determining saturated zone sampling depth intervals and how existing ground water data should be utilized or interpreted to evaluate VI risk.

3.2.1.5 Proximity to Preferential Pathways

Preferential pathways in the unsaturated zone (defined in Section 3.1.3) could allow rapid and/or laterally significant vapor transport. The bedrock outcrops are an example of naturally occurring preferential pathways. To the extent it is feasible and safe (e.g., drilling near utilities that could be damaged or pose an explosive or toxic threat), VI investigations should determine the proximity of contaminated ground water to unsaturated preferential pathways. The 30- or 100-foot critical distance criteria (see Section 2.4.3) may not be adequately conservative where preferential pathways connect buildings with areas of subsurface NAPL contamination or ground water/soil concentrations indicative of the presence of NAPL (e.g., plume source area with suspected NAPL is more than 100 feet side gradient of buildings but buried utility bedding connects it with buildings). This is more likely a concern for contaminants that do not aerobically biodegrade readily or where large quantities of product have been discharged.

3.2.1.6 Potential for Contaminant Degradation

Many contaminants associated with PHCs, including BTEX compounds are readily biodegraded in the vadose zone. As such, they are less likely than chlorinated compounds to complete the VI

to IA pathway. Even where light non-aqueous phase liquid (LNAPL) occurs in close proximity to buildings, rapid biodegradation in the vadose zone may preclude a complete pathway. Biodegradation of PHC contaminants is discussed in Chapter 5.

3.2.2 Use of Pre-Existing Ground Water Data

In many situations, shallow ground water data are already available prior to initiation of a VI investigation. The data may be from properly constructed monitoring wells or from alternative ground water sampling methods. In deciding whether existing data are sufficient, give consideration to the site-specific conditions.

The likelihood of significant vertical changes in ground water quality near the water table, the sampling method used, the construction of existing wells sampled (e.g., screen length and placement across water table), the type of contaminants present and/or heterogeneity of the vadose zone and shallow saturated zone media should be evaluated in determining whether existing data are sufficient.

For example, if an existing well was sampled using a method that will vertically average the sample and the well is screened across more than 10 feet of the saturated zone and site data suggests that contaminant concentrations are higher in close proximity to the water table, it may be prudent to obtain more depth discrete data. Obtaining such data is more important where conditions are not favorable for biodegradation in the vadose zone or for contaminants not likely to biodegrade or attenuate in the vadose zone.

3.2.2.1 *Interpolation of Nearby Data*

Use surrounding data points to construct contaminant iso-concentration maps if ground water data directly upgradient from the building are not available. However, this should only be done if data points are available on at least two sides of a building. Complex geologic settings or the anticipated presence of steep concentration gradients warrant a denser sampling grid. For additional technical guidance see Section 3.2.3.1 below on sampling locations.

3.2.2.2 *Use of Drinking Water Well Data*

VOCs in water supply wells above the Ground Water Quality Standards (GWQS) should trigger a ground water investigation, which may lead to a VI investigation.

3.2.3 Obtaining New Ground Water Data to Evaluate the VI Pathway

If the evaluations discussed above indicate that new or additional ground water data are needed to complete the VI investigation, the goal of the sampling effort should be to determine volatile concentrations in shallow ground water beneath or near potential receptors. Shallow ground water as used here is a relative term and refers to the first contiguous saturated zone encountered below the surface (in overburden or bedrock), that can be readily sampled using acceptable methods such as those described below and in the Department's FSPM (NJDEP, 2005a or latest version).

3.2.3.1 *Sampling Depth Interval Guidance for Multiple Sampling Methods*

An existing, permitted monitoring well may be adequate for evaluating the appropriate depth interval(s) if the screen/open borehole intersects the water table throughout the year (i.e., a water table well), and the sample from the well is representative of 10 feet or less of the water column in the well. For new water table wells installed as part of a VI investigation, a 10 foot screen is generally recommended unless this conflicts with other site investigation objectives (i.e., water table may fluctuate more than the 10 foot screen).

If a perched water table exists above the regional water table, collect samples from both the perched zone and regional shallow aquifer in most scenarios. Sample perched saturated zones that are laterally contiguous under/near buildings, exist year round and are below nearby building slabs if they are of sufficient thickness to obtain a sample. Use professional judgment in situations that are more complex; however, in the above scenario, sampling of the regional water table may not be vital to investigating the VI pathway.

In the following situations, the Department recommends vertical profiling of volatile concentrations in shallow ground water (e.g., multi-depth sampling within a well or temporary boring) to determine whether additional investigation of the VI pathway is needed. However, other multi-depth sampling approaches can also be used in the first two situations listed below; these could include well pairs/clusters or, if approved pursuant to N.J.A.C. 7:9D-2.8, multi-screened wells. For more information on multi-screened wells, see Section A.6.1.4.7 in the FSPM at <http://www.nj.gov/dep/srp/guidance/fspm/pdf/chapter06g.pdf>.

Vertical profiling with regard to a VI investigation is recommended as follows:

- A clean water lens is likely to be present above an already identified plume
- A site-specific GWSL will be used
- Direct push, short interval temporary wells, or any other discrete/small-interval ground water sampling method within a single boring or well is used to obtain new data to evaluate this pathway

In the above situations, conduct vertical profiling in at least one boring or well, preferably near the centerline of the plume. Multiple borings/well locations are appropriate where a large number of buildings overlie a large plume, especially if the investigator will claim that a clean water lens justifies a decision to cease further VI investigation. If a large area of impermeable surface cover occurs over a plume down gradient of where a clean water lens has been documented, at least one additional downgradient location for vertical profiling, close to the centerline of the plume, it is appropriate to confirm the continuing presence and thickness of the lens. This downgradient confirmation is especially critical if the clean lens was less than six feet thick in the upgradient location(s).

Vertical profiling and other multi-depth sampling of shallow ground water contamination may enable a more precise evaluation of the current and potential future risk of VI in some situations. For example, if the thickness of a clean water lens is shown to be increasing in the down gradient direction due to infiltration and recharge, this indicates a decreasing VI risk for development of undeveloped land down gradient that overlies the plume.

Sections 3.2.1.1 through 3.2.1.3 address the processes and site characteristics that favor the formation of a clean water lens. Development of the CSM should include evaluation of whether a clean water lens is likely to be present and/or if volatile levels below the GWSL are likely to be at or near the water table. See Sections 3.2.1.1 and 4.3.3, respectively, for Department procedures on documenting a clean water lens and data evaluation guidelines.

Where vertical contaminant profiling is done specifically for a VI investigation to establish a clean water lens, sample within the top 6 feet of the saturated zone. Site-specific considerations discussed below may warrant extending the total depth interval for profiling within a well or temporary boring to the top 10 feet.

3.2.3.2 Direct Push and Alternative Ground Water Sampling Methods

Alternate and direct push ground water sampling methods are often well suited for VI investigations especially if attempting to determine the depth of the interface between a shallow clean water lens and an underlying plume. If the sampling method does not affect sample quality and vertical profiling using direct push methods does not cause cross-contamination of samples during advancement in the same borehole, use data from temporary wells for VI investigations.

At least two samples from the top 6 feet of the saturated zone are recommended to establish that a clean water lens exists. Target the zero to 3-foot and 3- to 6-foot intervals from the top of the saturated zone. However, small changes of these intervals are appropriate if a sufficient volume of water cannot be obtained or if site-specific data support sampling alternate intervals. As discussed above, obtain one additional sample from the 6- to 10-foot interval below the water table (bwt) where significant drops in the water table elevation are likely. All the sample locations and intervals shall be accurately mapped and documented.

3.2.3.3 Ongoing Ground Water Monitoring

After an initial VI investigation has been completed, long-term ground water monitoring to reevaluate the VI pathway may be appropriate in some situations. Consider ground water monitoring, based on professional judgment, where ground water exceeding the GWSL is close to, but not currently within, the applicable critical distance criterion from a potential building if it is likely to migrate to within the critical distance criterion. Monitoring other media (e.g., SSSG, IA or exterior soil gas for undeveloped properties) can potentially substitute for, or supplement, ground water monitoring.

3.3 Soil Gas Sampling

The distinction between sub-slab, near slab and exterior soil gas sampling is critical for the investigation of the VI pathway. SSSG samples are collected from inside a building, while near slab and exterior soil gas samples are collected outside the building. A soil gas investigation shall be conducted using SSSG samples as the primary tool in the assessment of the VI pathway [N.J.A.C. 7:26E-1.18(c)2]. Near slab soil gas sampling is only recommended when specific technical issues make SSSG sampling impractical (e.g., very high water table) or explicitly

recommended in this technical guidance. See Section 3.3.2.1 for additional discussion on alternative soil gas sampling approaches.

3.3.1 Sub-Slab Soil Gas Sampling

3.3.1.1 *Application*

SSSG sampling can be useful for assessing the VI pathway from several perspectives.

The primary utility for collecting SSSG samples is to assess if there is a potential for a complete VI pathway to exist. A VI pathway is considered complete only when:

- A source of vapors, related to a discharge (e.g. soil and/or ground water plume), is identified; and
- A pathway connects the source to potential human receptors inside a building.

Elevated contaminant vapors in a sub-slab gas sample indicate that the pathway may be complete; however, low levels or the absence of volatile organics in a SSSG sample does not automatically imply there is no VI risk (see additional discussion in Section 3.3.1.2).

Use the results of SSSG sampling to assess whether the VI pathway is likely to pose a potential IA risk for a particular building. This may occur when the source of the vapors is a contaminated ground water plume containing volatile compounds under or in close proximity to the building in question. When employing SSSG sampling, the investigator should consider possible impacts from vapor clouds. This is a condition where contaminants move downward into the sub-slab area from the IA.

3.3.1.2 *Investigative Considerations*

Consider a number of factors when utilizing SSSG data. Preferential pathways, such as utility trenches, allow horizontal movement of vapors beneath and into buildings. In these cases, infiltration of vapors through openings in the sidewalls (e.g., utility penetrations) of a basement may represent a pathway for VI. As a result, the absence of elevated SSSG levels does not automatically imply that the VI pathway is incomplete. Under these conditions, near slab soil gas samples collected between the zone of soil contamination and the building's slab (or along preferential pathways) may be more appropriate than SSSG samples.

In situations where an earthen floor exists (instead of concrete), the provisions for SSSG sampling are not appropriate. As a rule, use SSSG sampling when the basement slab covers 50% or more of the building footprint. In these situations, it may be prudent to collect a combination of SSSG samples from the concrete area and IA samples from the crawl space overlying the earthen floor.

The investigator may also elect to collect SSSG and IA samples concurrently where sensitive populations, such as schools, child care centers or residential properties are involved. To prevent the SSSG sampling process from potentially affecting the IA samples, collect the IA samples prior to the SSSG samples.

SSSG sampling may also not be appropriate when a high water table exists near the base of the concrete slab (less than 2 feet). Typically, vapors migrate through the most permeable and driest material, but may also migrate along utility pathways beneath the slab. Depending on the analytical method, high moisture content in the soil gas sample can “mask” results, particularly polar compounds. If the capillary fringe is in contact with the slab, SSSG samples may not be representative. Additionally, low gas permeability may limit or restrict the flow of soil gas and thus increase the likelihood of leakage.

SSSG samples can be collected when ground water is as close as two feet below the building’s concrete slab if the following occurs:

- The seasonal high water table does not reach the building’s concrete slab;
- The water table does not extend into fill material placed directly under the building’s concrete slab as part of construction; and
- The capillary zone does not reach the building’s concrete slab (see Section 2.2.1).

Consider stratigraphy of the subsurface soil profile and soil types near the building, both naturally occurring and manmade. Low permeability layers, either natural or as part of the building’s construction may restrict migration of vapors from a ground water contamination source and result in relatively clean SSSG samples even though the underlying ground water is contaminated. Note that vapors may still enter the building through utility trenches or other preferential pathways if they bisect or circumvent the low permeability layer.

3.3.1.3 Analytical Methods and Parameters

The sample container normally utilized for the collection of SSSG samples is the 1-Liter passivated stainless steel canister. Six-liter canisters may also be employed. The SSSG samples can be analyzed using USEPA Method TO-15 (or other appropriate certified methods). Sampling with Automatic Thermal Desorption tubes and analysis by USEPA Method TO-17 is also acceptable.

Sample containers other than stainless steel canisters can be employed when screening or preliminary results are appropriate. Base all VI decisions regarding no further action at a building on data from a certified analytical method. The investigator can utilize a Tedlar[®] bag for sample collection and analyze the samples with a field gas chromatography (GC) or mobile laboratory. If a Tedlar[®] bag is used it will necessitate the use of a “lung box” and vacuum pump to draw a SSSG sample. Alternately, use glass or Teflon[®] syringes. As with the Tedlar[®] bags, analyze syringe samples with a field GC or mobile laboratory. The holding time for Tedlar[®] bags should not exceed 3 hours. USEPA SW-846 Method 8260B is the most common method utilized for field screening of air samples.

Analyze the initial set of SSSG samples from a building for the full parameter list of the applicable analytical method (based on Department procedures). Given an appropriate technical justification (e.g., large existing dataset), the investigator may consider not applying this provision and to utilize a reduced parameter list based on the COCs and related degradation

compounds associated with the site. Subsequent SSSG samples collected from a building may be analyzed for the site COCs (including degradation compounds).

Inform the Department of any compounds exceeding the applicable SGSL in the SSSG that are not COCs by calling the NJDEP Hotline. The Department will assess potential off-site contamination independent of the current investigation.

3.3.1.4 Leak Check

Perform leak tests on the soil gas probe and all fittings of the sampling train for the SSSG sampling event prior to collecting a soil gas sample. The leak test serves as a quality control measure to evaluate the potential for dilution of a sample from ambient air.

If multiple soil gas probes are installed during a sampling round, and leak tests performed on the initial probes indicate sample integrity, the investigator may reduce the number of probes that are tested.

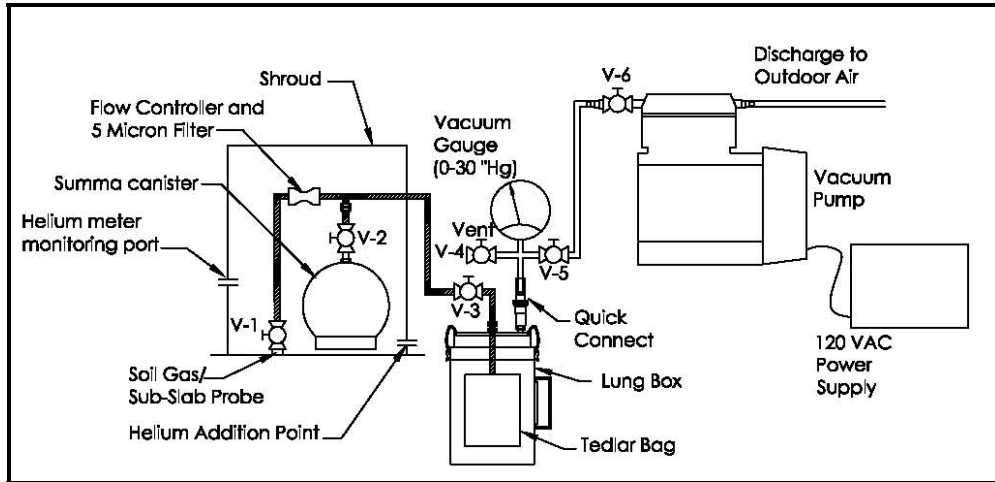
To verify the integrity of the seal, a tracer compound (e.g., helium or sulfur hexafluoride) is used. Helium is the preferred tracer as it is readily available, non-toxic, and easily measured in the field provided high methane levels are not present (false positives). Sulfur hexafluoride is an effective tracer, but requires a specialized instrument for detection that may not be readily available. It is also of concern as a greenhouse gas.

One method employs a shroud placed over the soil gas probe and the sample train. An inert tracer gas (such as helium) is released into the shroud with a target concentration of 10 - 20% (McAlary, et al., 2009).

With the canister valve closed, collect a soil gas sample using a Tedlar[®] bag. A leak is occurring when the helium concentration is greater than 10% of the concentration within the shroud. In this case, the leak must be fixed and the leak check repeated.

Independent of the leak check on the soil gas probe, conduct a shut-in test of the sampling train at each location, during each sampling event to verify aboveground fittings do not contain leaks. A shut-in test consists of assembling the above-ground apparatus (valves, lines, and fittings downstream of the top of the probe), and evacuating the lines to a measured vacuum of about 100 in-H₂O, then shutting the vacuum in with closed valves on opposite ends of the sample train. The vacuum gauge was observed for at least 1 min, and if there was any observable loss of vacuum, the fittings should be adjusted as needed until the vacuum in the above-ground portion of the sample train does not noticeably dissipate (McAlary, et al., 2009).

The one exception to this provision is when the sampling train is contained within the shroud as part of the leak check on the soil gas probe.



Helium shroud

Figure 3-1
Schematic diagram of sampling train using leak detection and photograph of helium shroud with Summa Canister (courtesy Geosyntec Consultants)

3.3.1.5 Sample Flow Rate

When a Tedlar[®] bag or syringe is utilized in combination with a field GC or mobile laboratory, the flow rate for sample collection should be based on the professional judgment of the investigator, but not in excess of 200 milliliters per minute (to avoid potential short circuiting or desorbing volatile organics off of the soil particles). In addition, a tight seal between the sample point and slab should be verified via leak check to prevent IA from mixing with the soil gas sample. For these reasons, do not take instantaneous or grab samples.

For stainless steel canisters, the sample flow rate should be a maximum of 200 milliliters per minute, which corresponds to a sample time of 5 minutes for one liter canisters. Once again, this maximum flow rate has been established due to the concern over short-circuiting. One or 6-liter stainless steel canisters are ordered from the laboratory under vacuum with pre-set regulators based on the sample time prescribed by the investigator.

It is not necessary to retain residual vacuum in the stainless steel canisters (equilibrium with the ambient barometric pressure) upon completion of the soil gas sample provided the sampler is present during the entire sampling event.

3.3.1.6 Calculating Purge Volumes

Prior to attaching the sample container, purge the vapor probe or borehole by drawing 3.0 volumes through the probe and the entire sampling train. Calculate the volume as follows:

$$\text{Purge Volume} = 3.0\pi r^2 h$$

where r is the inner radius of the probe and connecting tubing, and h is the length of the probe and the entire sampling train. The investigator should use a low purge rate with a maximum of 200-ml per minute.

3.3.1.7 Number and Location of Sample Points

For a typical single family residential building (approximately 1500 ft² foundation footprint), two vapor probes are recommended due to scientific research on spatial variability. Ideally, the sample probes should be near the center of the slab and equidistant from each other relative to the outer wall. However, a secondary location can be along the perimeter of the building usually no closer than 5 feet to the outer wall and biased towards the ground water plume or source material. For larger residential or non-residential buildings (or other unique conditions in the subfloor or construction of the foundation), utilize the table below as a minimum number of samples and add additional samples based on the building-specific features and conditions provided below the table.

Sub-slab sampling requirements cannot be based on area alone. The determination of the necessary number of sub-slab samples to characterize the impacts to a building from VI will vary from building to building due to various features and uses of the building. Evaluate the features and uses of a building based on professional judgment to determine the number of sub-slab samples.

Table 3-1
Recommended Minimum Number of Sub-Slab Soil Gas Samples

Square footage of floor	Number of Sub-Slab Soil Gas Samples
Up to 1,500	2
1,501 to 5,000	3
5,001 to 10,000	4
10,001 to 20,000	5
20,001 to 50,000	6
50,001 to 250,000	8
250,001 to 1,000,000	10
>1,000,000	12+

Features and conditions that may require altering the number of samples or biasing a sample location include, but are not limited to the following:

- Presence of sensitive populations
- past usage (e.g., dry cleaners, vapor degreasers, underground storage tanks)
- building construction (separate foundations, type of slab, footers, utility lines etc.)
- presence of earthen or damaged floors
- presence of sump pits
- requests from building owner
- elevator pits
- portion of building overlying or contacting the highest levels of VOCs
- areas of greatest exposure (play rooms, family rooms, class rooms, offices)
- homogeneity and composition of sub-slab material

All of the features of a building should be considered when determining the number of sub-slab samples. For example, a 25,000 ft² strip mall separated into five individual tenant spaces and separate foundations with one space operating as a daycare may require up to 15 samples, where a stand-alone 25,000 ft² building that is mostly warehouse space with a single slab may only require 6 samples.

The investigator should consider the tenant and/or owner preferences for sub-slab sample locations. To minimize potential damage to flooring, it may be necessary to select a location in a closet or utility room (where floor covering is less visible or not present).

Due in part to spatial variability, the results of the soil gas samples are not averaged across the subsurface around or under a building. Therefore, each data point is evaluated independently.

3.3.1.8 Sample Frequency

Based on site-specific conditions, the investigator may determine that a second sampling round may or may not be necessary. Supplemental environmental data (e.g., seasonal ground water level, IA, weather conditions) examined as an MLE approach may eliminate (or indicate) the need for a second round of SSSG sampling.

3.3.2 Alternative Soil Gas Sampling

As previously noted, a soil gas investigation should be conducted using SSSG samples as the primary tool in the assessment of the VI pathway. Near slab soil gas sampling is only acceptable when specific technical issues make SSSG sampling impossible (e.g., very high water table, occupant refusal) or explicitly permitted in this technical guidance.

3.3.2.1 Application

Near slab soil gas sampling has limited applicability in the evaluation of the VI pathway and is not recommended as a primary investigation tool for assessment of the VI pathway on existing buildings (see Section 3.3.2.2). This investigation tool is limited because significantly different conditions for the migration of vapors may exist outside of the building as compared to beneath the building slab. Examples of the differences include:

- the lack of influence of the building HVAC system
- mass transfer to the uncovered surface
- heterogeneity of fill used around the building
- utility trenches acting as preferential conduits
- soil type
- soil moisture

These differences make near slab soil gas data more appropriate in most cases as a field screening tool or as a supplementary line of evidence in the evaluation of the VI pathway.

The collection of SSSG samples is the preferred tool for evaluating the risk that VI may be occurring at an existing building. However, the cooperation of the building occupants and/or owners to do SSSG sampling is not guaranteed. Thus, near slab soil gas sampling may be an alternative to sub-slab sampling when an alternative approach is required. Use near slab soil gas sampling for comparison to the SGSL when specific technical issues make SSSG sampling impossible (e.g., very high water table, presence of a gas vapor – not moisture - barrier) or the building owner refuses access. If used, provide justification to document why the SSSG sampling was not feasible.

Exterior soil gas sampling has limited applicability in the evaluation of the VI pathway for existing buildings. This investigation tool is limited because significantly different conditions for

the migration of vapors may exist outside of the building as compared to beneath or in proximity to the building slab (as noted above). Thus, exterior soil gas data are more appropriate as a field screening tool or as a supplementary line of evidence in the evaluation of the VI pathway.

Do not utilize exterior soil gas sampling as a stand-alone determination for VI evaluation of existing buildings. Analytical results from an exterior soil gas sampling may be utilized as part of an MLE approach to determine whether the VI pathway is currently complete for a particular building. If the concern is related to future use of an undeveloped parcel, exterior soil gas results are appropriate to determine if the pathway may be complete when a building is constructed.

Exterior soil gas sampling is more often used to identify/delineate volatiles in the subsurface, update the CSM and assess the magnitude or extent of biodegradation of hydrocarbons. A soil gas survey is not intended to be a substitute for conventional methodology (e.g., ground water sampling), but instead as a screening tool to enable conventional methods to be used more effectively.

3.3.2.2 Investigative Considerations and Procedures

For near slab or exterior soil gas sampling results to be accepted as a line of evidence in an assessment of the VI pathway collect the soil gas samples in the vadose zone at the depth within one foot above the capillary fringe and a minimum of 5 feet below the surface. However, a shallow ground water table may prevent the collection of representative or valid soil gas samples due to high moisture content in the soil which can reduce gas permeability and/or dilution due to atmospheric air being drawn down from the surface. In these situations an alternative would be for the investigator to collect soil gas samples from below existing large impervious surfaces (e.g., garage floors, patios, parking lots, roads and driveways).

Information on the sample containers, purge volumes, leak detection, sample flow rates and parameters that are recommended for near slab and exterior soil gas samples being used to support a VI investigation are similar to those recommended for SSSG sampling. Therefore, for information regarding these items, please refer to Section 3.3.1 of this document. Additional information on soil gas sampling procedures is provided in the Department's FSPM (NJDEP, 2005a or latest edition).

3.3.2.3 Number and Location of Samples

Any decision on the number and location of near slab soil gas sample points should start with an evaluation of the CSM. For example, if there are indications from the ground water characterization that there could be large lateral changes in concentrations over short distances near a building, there may be a case for increasing the number of sample points.

If near slab soil gas samples are being collected as a line of evidence in the assessment of the VI pathway, samples should be collected from a minimum of two sides of the building in question. Samples should be spaced horizontally along the perimeter of the building, at two to three times the depth to ground water (NJDEP 2005a). Locations will be in part dictated by the existing conditions around the building perimeter (e.g., other buildings, landscaping and access issues) and the location of the ground water plume.

If two soil gas sample locations have two to three orders of magnitude difference in concentration, collect at least one additional sample between the two points.

3.3.2.4 *Undeveloped Parcels and Future Use*

When the potential for VI extends to undeveloped parcels, implement a VI investigation to assess the impact on future use. An MLE approach may be appropriate in these situations to assess the potential for VI. The lines of evidence may include the delineation of the ground water plume, analysis of deep soil gas samples (just above the water table) using a grid sampling approach and biased towards the highest concentrations within the ground water plume, implementation of pneumatic testing (soil permeability) and/or soil stratigraphy.

In situations where the future use is restricted by an institutional control, an alternative approach may be proposed, possibly postponing investigation to some point in the future when development is being considered.

3.4 **Conducting a Building Walkthrough and Survey**

A building walkthrough is a critical element of any VI investigation that includes IA or SSSG sampling. Components of a building walkthrough include:

- identification of potential background sources of volatile compounds
- assessment of the building construction (e.g., concrete slab, air flow)
- recognition of points of potential VI into a building
- identification of possible sample locations
- determination of building pressure/ventilation in large buildings
- education of the occupants about VI and sampling procedures

If possible, the building walkthrough should be conducted prior to the day of the IA or SSSG sampling event. This advance timeframe allows the investigator to identify and eliminate (to the extent practical) potential background sources of IA contamination. It also permits the investigator to confirm the sample locations with the occupants ahead of the scheduled sampling episode.

One of the tools utilized in a VI investigation is the *Indoor Air Building Survey and Sampling Form* (Appendix D). The survey form allows the investigator to record information about the building, the occupants and potential sources of IA contamination.

The *Indoor Air Building Survey and Sampling Form* is broken down into eight sections:

- Part I - Basic information on the occupants of the building
- Part II - Characteristics of the building under investigation
- Part III - Identification of outside contaminant sources that may exist near the building being investigated
- Part IV - Identification of potential indoor contaminant sources found in the building

- Part V - Survey of miscellaneous items related to building activities that may impact IA quality
- Part VI - Documentation of sampling information (completed the day of the sampling event)
- Part VII - Existing meteorological conditions during the sampling event
- Part VIII - Documentation of any general observations noted during the sampling event that do not fit into the above categories (i.e., occupancy exposure times)

3.4.1 Identification of Potential Background Sources

As discussed in Chapter 4, investigating the VI pathway can be complicated by the impact of background sources. Differentiating common building sources that could affect IA quality from those associated with contaminated ground water or subsurface soil can be a challenge in the evaluation of the VI pathway.

An effective tool for pinpointing background sources of IA contaminants during a building walkthrough is the use of handheld field screening instruments, such as the photoionization detector (PID). These instruments can provide useful information for critical decisions in the field (e.g., identifying solvent cans as potential background sources, determining sampling locations). Factors that should be evaluated in selecting a screening instrument for VI investigations include the instrument detection limit for the COC, the eV of the lamp, the ionization potential of the COC and the calibration gas used for the instrument.

When background sources of IA contamination are identified and removed from a building, it would be prudent to ventilate the rooms affected in advance of the sampling event. Terminate this ventilation at least 24 hours before commencement of the IA sampling event to allow ventilation to return to normal operating conditions. As discussed in Chapter 4, these chemicals can be retained in materials found in the building (e.g., carpeting) and subsequently released over time.

3.4.2 Recognition of Points of Vapor Intrusion in a Building

The entry of organic vapors into a building is due to the infiltration of contaminants through the floor and walls that are in contact with the soil. Usually, vapors can enter a building through poorly sealed utility lines that penetrate the foundation. Other contaminant pathways are through cracks in the walls and floors, sumps, elevator pits, around the wall/floor juncture of floating floor construction or other breaches in the walls or slab.

The *Indoor Air Building Survey and Sampling Form* asks a series of questions that are designed to assist in the identification of potential points of VI. Part II inquires about the building construction. Note any obvious breaches in the walls or slab in the basement (or lowest floor) in Part VIII (General Observations) of the *Indoor Air Building Survey and Sampling Form*. The investigator should also examine and note the point at which utility lines enter the building.

3.4.3 Identification of Possible Sample Locations

The building walkthrough offers an opportunity for the investigator to identify possible sample locations that fit the defined investigative goals of the VI investigation. The identification of basement or foundation VI entry points, as outlined above, allows the investigator to target worst case sample locations for SSSG and IA sampling. If additional samples are being collected, the determination of those portions of a building where occupants spend the greatest amount of time (e.g., residential living room or commercial office space) during the walkthrough allows the investigator to identify areas that represent the greatest period of exposure to the occupants that can then be used in the evaluation of IA sample locations.

For the selection of sub-slab sample locations, identify the presence of any utilities (e.g., sewer, water, radiant heat) under the slab during the building walkthrough so those areas can be avoided for safety reasons when determining potential sample locations. The selected sample location(s) should be chosen in consultation with the property owner. Additional information on identifying sample locations is presented in Sections 3.3 and 3.5 of this guidance.

3.4.4 Education of the Occupants on Vapor Intrusion and Sampling Procedures

One of the roles of the investigator when collecting samples within the impacted areas of a building or specific leasehold is to educate the occupants about the VI pathway. During the building walkthrough, occupants may raise a number of issues that the investigator should be prepared to answer. Refer to the Department's Vapor Intrusion websites, <http://www.nj.gov/dep/srp/guidance/vaporintrusion/> for a discussion on how to conduct community outreach during the investigation of the VI pathway. The fact sheet, *Evaluating Indoor Air near VOC Contaminated Sites* (Appendix E) may provide further assistance. The investigator should inform the property owner during the walkthrough that utility (e.g., electric, gas) representatives may visit their property to mark out the location of area utility lines prior to the sampling event.

A one-page advisory paper entitled *Instructions for Occupants - Indoor Air Sampling Events* (Appendix F) provides building occupants with a list of actions that should be avoided before and during the sampling event. *The Instructions for Occupants - Indoor Air Sampling Events* sheet should be made available to the occupants at least several days prior to the sampling event. Document any departures from the instructions noted during the sampling event on the *Indoor Air Building Survey and Sampling Form*.

3.5 Indoor Air Sampling

The collection of IA samples is necessary whenever the potential for VI exists and other investigative tools cannot eliminate the VI pathway. In addition, IA samples are appropriate for post-mitigation verification purposes.

3.5.1 Application

The primary utility for collecting IA samples is to assess if a complete VI pathway exists. A VI pathway is considered complete only when:

- A source of vapors related to a discharge is identified; and
- A pathway exists connecting the source to people inside a building.

In most cases the collection and analysis of IA samples is determined to be necessary based upon soil gas and/or ground water results. In determining if the VI pathway related to a discharge is complete, the collection and analysis of IA samples are necessary when the soil gas results exceed the SGSL at a building. The investigator is only required to conduct an IA investigation when COCs are detected in the subsurface in excess of the applicable VI screening levels or other triggers identified in N.J.A.C. 7:26E-1.18(a). The application of crawlspace samples is discussed in Section 2.2.3.

When compared to the other investigative tools available, IA sampling represents the most direct measure of human exposure for the VI pathway.

A multitude of sources that originate both inside and outside any building affects IA quality. Assess background contamination whenever IA samples are collected. A detailed discussion on background contamination can be found in Chapter 4. In addition, a variety of meteorological, temporal and structural factors can influence IA concentrations resulting from VI.

3.5.2 Investigative Considerations

As it relates to building interior investigations for the VI pathway, the investigator has three main options for collecting IA samples in relationship to other VI samples.

Option 1: The investigator can collect and analyze IA samples after the results of sub-slab, near slab, or exterior samples are known. Under this option, an IA sample is collected and analyzed if soil gas results are greater than applicable SGSL for COCs.

Option 2: The investigator can collect and analyze both SSSG and IA concurrently. The investigator can use Option 2 for any building.

Option 3: To minimize the inconvenience to property owner, tenants, and/or occupants, the investigator can collect both SSSG and IA concurrently. Submit the SSSG and IA samples to the certified laboratory for analysis. However, only the SSSG samples are initially analyzed. Assuming that holding times are met, the IA samples would be analyzed if the SSSG results or building survey findings suggest that further investigation is warranted (a COC exceeding the SGSL).

The investigator can use a combination of sampling options in a VI investigation. For either Option 2 or 3, collect the IA sample first at the building undergoing investigation. This provision is designed to minimize influencing IA concentrations from sub-slab sampling. Once the IA sampling is completed, the investigator should collect the SSSG sample. Using a typical sampling process, the IA sample collection would be started on Day 1. Twenty-four (24) hours later (Day 2), the IA sample canister is closed and the investigator would collect the SSSG sample (usually 5-30 minutes).

It is recommended that the investigator collects SSSG (or near slab soil gas when substituted for sub-slab) and IA samples concurrently as part of a VI investigation for all buildings having sensitive populations.

The investigator should complete the *Indoor Air Building Survey and Sampling Form* (Appendix D). The data on this form are a critical part of evaluating MLE when IA samples are collected. The survey form should be initiated as part of the building walkthrough (conducted prior to the sampling event). In addition, the form is used to document the sampling event. Refer to Section 3.4 for additional information on the building walkthrough and the survey form.

In general, the investigator should not collect IA samples in a portion of a building where operations use, handle or store the same investigative COCs (e.g., dry cleaners, active gas stations, maintenance facilities and various industrial operations). In these situations, it is difficult to determine whether air contaminants present in a building are from operational activities within the facility or from VI. The investigator may consider other lines of evidence in evaluating VI exposures in these situations. The investigator should review the facility's Material Safety and Data Sheet (MSDS) and Hazard Communication Program to determine if a site's COC is used, handled, or stored in the building. Consider and address the potential for a change in the future use of the building in these situations (see Section 6.4.1).

IA samples should be collected concurrently with ambient air samples. Ambient air results are useful in the differentiation of background contamination from outdoor air.

The collection of ambient temperature and barometric pressure readings during the collection of IA samples including ambient air samples (or sub-slab pressure differential during SSSG sampling) are appropriate to verify data representativeness. For an ambient sample, there are several ways to obtain this information. One method is obtaining atmospheric pressure and temperature from the nearest weather reporting station. Two web sites that may be useful to the investigator are the National Oceanic and Atmospheric Administration, National Weather Service web site at <http://www.weather.gov> and the Weather Underground at <http://www.wunderground.com/>. Alternately, the investigator can bring portable meteorological instrumentation on site to obtain the information to assist with interpreting the data (MLE).

Obtain temperature for indoor samples using portable meteorological instrumentation with readings taken inside the building. Based upon spacing of the IA samples, it may be appropriate to record temperature readings for each sample location.

Larger commercial buildings may also require the same approach. However, the investigator should take into account that commercial/industrial buildings economize on energy by changing air exchange rates and temperature settings during evening, overnight and weekend periods, which can influence sample concentrations.

3.5.3 Parameters

The initial set of IA samples should be analyzed for the full parameter list of the applicable New Jersey certified analytical method as listed on the Department's website (http://www.nj.gov/dep/srp/guidance/vaporintrusion/method_to15_units_conv_table.xls). Given

an appropriate technical justification (e.g., large existing IA/soil gas data set), the investigator may consider utilizing a reduced parameter list based on the COCs and related degradation compounds associated with the site. Regardless of the approach utilized for the initial sampling round, subsequent IA samples collected from the same building may be analyzed for a reduced parameter list of the site COCs (including degradation compounds).

3.5.4 Sample Duration and Flow Rate

For the Department's currently approved TO15 Methods, 6-Liter stainless-steel canisters shall be used for the IA sample collection. Alternative sizes or types of sample containers are not acceptable for IA samples per the analytical method. For sensitive use buildings IA samples should be collected over a 24-hour period. A sampling time less than 24 hours may be substituted with proper justification, such as limited access or hours of operation. However, the minimum sampling duration should be 8 hours.

For commercial, retail, office, and industrial settings, IA samples are typically collected over a 24-hour period. However the investigator may shorten the sampling period to correspond to the average workday or the timeframe the building or floor of interest is occupied on a daily basis. The minimum sampling time is 8 hours with proper justification. Sampling times less than eight hours should be technically justified and proper consideration given to future use changes. In these cases, the investigator should evaluate shift length, the maximum exposed worker timeframe, number of shifts per day, and other factors in selecting a sampling period other than 24 hours.

Flow rates are to be set by the laboratory to match sampling time (e.g., 24 hours, 8 hours, etc.) and canister volume. Therefore, the sample time should be established in advance of the sampling event.

For samples collected using USEPA TO-17, the pump rate should be set so that the final calculated RL used by the laboratory shall be less than or equal to the RL for the Department's currently approved TO-15 Method. Care should be taken not to exceed the safe sampling volume for each volatile compound related to the sorbent(s) used. In addition, sampling in humid environments may result in an accumulation of moisture on the sorbent tube, which would further accelerate breakthrough. The laboratory should be consulted prior to sampling to determine the most appropriate sorbent and sampling volume.

The minimum sample collection time for the sorbent tubes is eight (8) hours. A twenty-four (24) hour sample collection time is the preferred sampling time, because it provides a longer time weighted average for exposure.

Grab sample results are not considered to be representative of IA quality with respect to evaluating VI pathway. Do not compare grab sample results to the IASL or RAL.

3.5.5 Number and Location of Samples

This section is a guide to assist the investigator in determining the number of IA samples to assess VI impacts for residential and nonresidential buildings. Obtain at least one IA sample

from the basement or slab on grade level of a building. Collect additional samples from upper floors based upon professional judgment.

Table 3-2 provides general information for determining the minimum number of IA samples for buildings of various sizes. Adjust the number of samples based on the building-specific features and conditions provided below in following table.

Table 3-2
Recommended Minimum Number of Indoor Air Samples

Square footage of floor	Number of Indoor Air Samples
Up to 1,500	1-2
1,501 to 5,000	2
5,001 to 10,000	3
10,001 to 20,000	4
20,001 to 50,000	5
50,001 to 250,000	6
250,001 to 1,000,000	7
>1,000,000	9+

The number of IA samples should not be based on area alone. The determination of the required number of IA samples to characterize the impacts from VI will vary from building to building due to various features and uses of the building. Evaluation of the features in a building should be assessed based on professional judgment to determine the number of IA samples required to assess the potential for VI. Features or conditions that may alter the number of samples or biasing a sample location include, but are not limited to the following:

- sensitive populations
- presence of earthen or damaged floors
- presence of cracked or damaged basement walls
- presence of crawl spaces
- presence of sump pits
- requests from building owner
- preferential pathways
- dividing of building floor into separate rooms or occupancy spaces
- utility or mechanical room with thru wall/floor utility line openings
- elevator pits
- portion of building overlying or contacting the highest levels of VOCs

- areas of greatest exposure (play rooms, family rooms, class rooms, offices)
- ventilation
- potential indoor sources of contamination

Any sampling approach should take into account the different exposure scenarios (e.g., child care center, residences, office, and warehouse) that exist within the building(s) and any sensitive populations that may be exposed to the contaminated vapors. Multiple IA sample locations may be necessary for multi-family residential, commercial and retail buildings. The rationale for the number of IA samples collected per building should be documented by the investigator.

All of the features of a building should be included as factors that will influence the number of IA samples. For example, a 25,000 ft² strip mall separated into five individual tenant spaces that are separately ventilated may be best evaluated with 10 samples, where a stand-alone 25,000 ft² building that is mostly warehouse space with a small office space and a single ventilation system may only need 5 IA samples to document IA quality.

For buildings with up to 1,500 ft² footprint (e.g., residences), the number of IA samples depends upon the improvements in the basement or lowest floor space. If the basement is generally open space that may or may not include a small separate utility/furnace area, one sample will likely be sufficient to characterize IA. If the basement were divided into two or more spaces, collect more than one IA sample.

When a basement is present, the investigator may also want to collect an IA sample from the first floor and crawl space (if present) to properly assess human risk or alternative vapor entries into a building. If COCs have not been detected above the applicable IASL in the basement then analyzing air samples on upper floors may not be necessary. Breathing zone height (3-5 feet) will be appropriate for the upper floor sample collection, whereas the basement sample should be positioned as close as possible to the source area (e.g., sumps, major cracks in slab). For multi-story buildings, consider collecting a sample from above the neutral pressure plane, if warranted.

Multi-family residential units involve a more careful review of the building features. Each ground level residential living space (e.g., duplex, row houses) with a basement or slab on grade should be considered a separate unit for IA sampling.

In general, collect one ambient (outdoor) sample per sampling event concurrently with IA samples to assist in evaluating background contaminant levels. Refer to Section 3.1.2.3 for placement of ambient air samples.

3.5.6 Sample Events

In most circumstances, seasonal variability in vapor concentrations necessitates collecting more than one set of IA samples from a building and an ambient air sample.

When IA samples are being collected as a primary assessment tool for the determination of the VI pathway, the sample event should take place between November 1 and March 31. Based on seasonal weather patterns, these dates are generally “worst case” conditions for VI to occur.

Assuming there are no other contradictory lines of evidence, the single round of indoor/ambient air samples should be able to determine whether the VI pathway is complete.

In situations where the initial indoor/ambient air samples are not collected during the November 1st through March 31st timeframe, a second round of samples should be collected during the worst case conditions. The one exception to this general rule is when a single round of sampling is conducted between April 1 and October 31 and each COC concentration is an order of magnitude or more below the IASL, then a second round of samples is not needed.

If the two sets of samples are collected and the results are inconsistent with respect to the appropriate screening level (i.e., one result above and one result below screening level), a third confirmation sample collected within the appropriate timeframe may be necessary based on professional judgment and MLE. The results cannot be averaged for comparison to the appropriate screening level. In addition, the investigator should evaluate other lines of evidence to ascertain the technical reasons for this discrepancy.

Once a trigger initiates a VI investigation (pursuant to N.J.A.C. 7:26E-1.18), the investigator cannot delay the collection of IA samples due simply to the time of year when the indoor/ambient air samples will be collected (in relation to the issues discussed above).

3.6 Investigative Reporting Requirements

The Technical Rules require the submittal of reports when a VI investigation or VI sampling has been conducted under the following scenarios (N.J.A.C. 7:26E 1.18(g)). For all documents prepared for the VI pathway, including letters sent to building occupants, report the soil gas and IA analytical results in units of $\mu\text{g}/\text{m}^3$ (micrograms per cubic meter). The analytical units of parts per billion by volume are no longer acceptable due to frequent unit conversion errors and misapplications.

Refer to the *Vapor Intrusion Timeline* (Appendix B) for additional information on required forms and deliverables.

3.6.1 VI Receptor Evaluation

N.J.A.C. 7:26E-1.18 specifies the requirement for the completion of a VI investigation as part of the VI receptor evaluation. The investigator shall submit an initial VI receptor evaluation and updated VI receptor evaluation report, as per N.J.A.C 7:26E-1.15. The required forms and instructions can be found at <http://nj.gov/dep/srp/srra/forms/>.

A summary of the VI Receptor Evaluation shall be included in the applicable report(s) provided to the Department with the following:

- A description of all buildings sampled with justification for those buildings where sampling was determined not to be necessary;
- A scaled map of the site and surrounding area that includes the following:

- The locations of all buildings and appropriate subsurface utilities (see Section 3.1.3) identified as part of the VI receptor evaluation in relation to the areas of known ground water contamination;
- The use of all buildings and whether they are occupied; and
- Highlights buildings that are used as residences, schools and child care centers;
- A description of all VI investigation and mitigation conducted, including all monitoring conducted to determine the effectiveness of the mitigation; and
- A description of all additional planned VI investigations.

3.6.2 VI Sampling

As per N.J.A.C. 7:26E 1.18(g), the investigator shall provide a detailed report of all VI sampling activities in the applicable remedial phase report submitted to the Department. The following information should be submitted to the Department after the VI sampling has been conducted with the next report submittal:

- A summary of the VI evaluation including the VI receptor evaluation information specified in Section 3.6.1 above;
- Copies of the *Indoor Air Building Survey and Sampling* form;
- Scaled site maps identifying:
 - the site, adjacent streets and appropriate subsurface utilities (see Section 3.1.3),
 - extent of the subsurface contamination (e.g., ground water plume),
 - buildings sampled and soil gas, IA and ambient air sample locations;
- Summary tables identifying all contaminants detected above the RLs with those values above the applicable screening levels highlighted;
- Photographs of sample locations (as appropriate) or other pertinent site features;
- Readings from field instrumentation;
- Any documentation, including scaled maps, on the assessment of preferential pathways;
- Scaled floor plans that note information that includes, the location of IA and SSSG samples, observed stains and major cracks in slabs, sumps, French drains, elevator pits, existing radon systems, chemical storage areas (or other potential background sources), HVAC systems and utility entrances into the buildings;
- An evaluation of sampling results in relation to the applicable VI screening levels and determine whether the VI pathway is of concern. Provide recommendations and an implementation schedule. Technical justification shall be included as to whether or not contamination is related to VI; and
- Clarification that the applicable analytical data and/or IA results have been provided to the Department, NJDHSS and the building owner/occupant as required under N.J.A.C. 7:26E-1.14 and 1.18.

3.6.3 Immediate Environmental Concerns

The following reports are required when a VI related IEC has been identified at a site.

IEC Engineered System Response Action Report

An IEC ESRA Report, submitted pursuant to N.J.A.C. 7:26E-1.14(c), shall include the following information:

- A description of all immediate response actions and ESRA that have been completed including the date that each action was conducted;
- A summary of all analytical data related to the IEC and the engineered response action;
- All maps and figures related to the IEC and the engineered response action;
- A description of the contaminant source control that will be implemented as required pursuant to N.J.A.C. 7:26E-1.14(d); and
- A Geographic Information System compatible map of the estimated area of ground water contamination prepared pursuant to the Department's Immediate Environmental Concern Technical Guidance.

IEC Contaminant Source Control Report

An IEC contaminant source control report, pursuant to N.J.A.C. 7:26E-1.14(d), shall include the following information:

- The remedial actions being implemented to remediate the IEC contaminant source;
- A monitoring plan for the mitigation system; and
- A monitoring plan for the wells or buildings located down gradient of the wells or buildings impacted by the IEC.

Detailed instructions and information on report requirements associated with a VI IEC are presented in the Department's Immediate Environmental Concern Technical Guidance that may be accessed at <http://www.nj.gov/dep/srp/guidance/>.

4.0 MULTIPLE LINES OF EVIDENCE AND DATA EVALUATION

One of the most difficult facets of investigating VI is the interpretation of the available information and the subsequent conclusions reached on the completeness of the pathway. The effects of background sources on the overall IA quality complicate the task.

VI from a discharged hazardous substance, hazardous waste, or pollutant to ground water or soil is a regulatory concern of the Department. Yet, how an investigator assesses whether IA is contaminated by a regulated discharge is quite different from other media. For soil and ground water, the determination that the media is contaminated is largely based on a single line of evidence – the analytical results of a sample. VI is a complex pathway where the identical results of analytical data collected from two sites can lead to different conclusions based on the site-specific MLE.

While it is appropriate to utilize the MLE approach in all phases of a VI investigation (consistent with the Technical Rules), the most critical point is in the determination of whether the VI pathway from a regulated discharge to a potentially exposed person is complete. Background sources can affect IA and soil gas quality, complicating the assessment of the VI pathway. According to the USEPA, background refers to constituents that are not influenced by the discharges from a site, and is usually described as naturally occurring or anthropogenic (USEPA, 2002a). For the purpose of this technical guidance, background will refer to any contaminants not directly resulting from subsurface VI related to a regulated discharge. In some cases, individual contaminants found in IA or soil gas may result from both subsurface VI and background sources.

Background sources are typically identified through the collection of upgradient or upstream samples for ground water and surface water respectively. With soil investigations, background samples are collected from areas of the site not impacted by current or historical operations and having similar soil characteristics. Building interiors do not generally provide for “upgradient” or “non-impacted” sampling locations to establish background IA levels. Thus, an alternative approach is necessary for IA and soil gas assessments to distinguish background sources from site related VI.

4.1 Background Indoor Air Sources

Background IA sources can be broken down into several categories – household activities, consumer products, building materials and furnishings, and ambient air pollution. The conveniences of life that people often take for granted can greatly affect IA quality. The numerous sources impacting the air quality of buildings warrants scrutiny since the average American spends over 90 percent of her or his time inside where chemical concentrations are often much higher than outside (USEPA 2001a).

Smoking tobacco products, parking a car in an attached garage, using a kerosene heater, burning scented candles, dry cleaning clothes - all these household activities contribute to potentially unhealthy chemical concentrations in the IA. Consumer products represent a second source of IA pollution that should be evaluated when assessing the contribution from VI. Mothballs and scented candles (1,4-dichlorobenzene), nail polish remover (acetone), rug spot cleaner

(tetrachloroethene or PCE), floor polish (xylenes), drain cleaner (1,1,1-trichloroethane) and gasoline (BTEX) are just a few of the examples.

Building materials and furnishings are another source of IA pollution, particularly when they are new. Whether it's carpeting, shower curtains, fabrics and draperies, furniture, building insulation or pressed wood products (particleboard, hardwood plywood and medium density fiberboard), IA quality can be significantly affected by volatile compounds and formaldehyde emanating from these products.

Numerous materials found in buildings, such as carpeting, fabrics and wallpapered gypsum board, can act as "sinks" that retain IA pollutants and subsequently release them over a prolonged period of time (Won, et al. 2000). Carpets represent a significant sink for non-polar volatiles, while virgin gypsum board interacts primarily with highly polar volatiles.

Outdoor air typically enters a building through infiltration, natural ventilation and mechanical ventilation. Yet, studies have shown that common organic pollutants are 2 to 5 times higher inside a building compared to levels in the ambient air (USEPA 1987). Over the last three decades since the passage of the Clean Air Act in 1970, the pollutant concentrations in the outdoors have been greatly reduced. Despite this turnaround, ambient air in urban environments (and other unique circumstances) does require careful consideration when evaluating IA results.

4.2 Components of a Multiple Lines of Evidence Approach

This technical guidance relies on a MLE approach when evaluating VI data and assessing potential background sources. This approach employs a series of primary and secondary factors that collectively gauge the often confounding pollutants found in IA and determine with reasonable certainty the contribution from VI.

Utilizing this methodology, the primary factors (discussed below) provide more significant evidence when compared to the secondary factors. The MLE approach is not designed to be a mathematical calculation, but rather a professional judgment based on a progression of empirical facts, some more relevant than others.

The investigator is reminded that the CSM is an integral part of assessing the VI pathway. Thus, the MLE approach should be utilized to support the conclusions of the CSM.

4.2.1 Primary Factors

The primary factors (in no particular order) for assessing the VI pathway are provided below.

4.2.1.1 Site-Specific Contaminants of Concern

For the VI pathway, ground water contamination is the principal trigger requiring a VI receptor evaluation and investigation. Thus, a well delineated ground water plume (or subsurface soil contamination, if applicable) with identified chemical contaminants can greatly limit the scope of any investigation. Potential degradation products must be included in the COC list.

Unfortunately, VI investigations are often conducted with limited information where ground water or subsurface soil data are seldom extensive or complete. Insufficient data may prevent COCs from being determined prior to the collection of IA samples. The investigator should analyze soil gas and IA samples collected during the initial round at each building undergoing a VI investigation for the full list of parameters (based on the methodology) and not a reduced list. Given an appropriate technical justification (e.g., large existing dataset), the investigator may consider not applying this provision and to utilize a reduced parameter list based on the COCs and related degradation compounds associated with the site. Subsequent phases of soil gas and IA sampling at each building undergoing a VI investigation can employ a reduced parameter list.

4.2.1.2 Sub-slab soil gas sampling

Collecting vapor samples from below the building's slab is an excellent tool for differentiating contaminants originating in ground water and subsurface soils from those associated with background sources. Follow the Department's procedures for collecting SSSG samples, as outlined in Section 3.3.1, to utilize the data in the evaluation of background pollution.

SSSG samples, collected concurrently with IA samples from the same building, will allow for a comparison between the data. The investigator should evaluate the COCs found in the ground water and subsurface soils (and their concentration ratios relative to each other). Do they generally agree with the results from the SSSG and IA samples? Agreement between these different sets of data would indicate that the VI pathway is complete.

Frequently, pollutants will be found in the IA, but not the sub-slab samples. In these cases, the compounds are likely originating from background sources unrelated to VI, and the occupants should be directed to consult with the local health department on ways to reduce background pollution.

A concentration gradient between the sub-slab and IA samples (greater than fifty times higher in the sub-slab based on an attenuation factor of 0.02) suggests that the VI pathway is complete. Conversely, higher concentrations within the building (when compared to sub-slab results) would indicate that a secondary background source is likely present inside. This scenario, however, does not eliminate the fact that the VI pathway may still be affecting IA quality within the building.

The investigator shall consider the presence of preferential pathways consistent with the Technical Rules (N.J.A.C. 7:26E-1.18(b)). The VI pathway may be complete even though low sub-slab concentrations are detected. Vapors, particularly from contaminated soils, may migrate along preferential pathways above the depth of the building's slab. Thus, contaminated vapors may adversely impact a building's IA quality without the presence of elevated sub-slab vapors.

4.2.1.3 Ambient (outdoor) air sampling

Collect a minimum of one ambient air sample during every IA sampling episode. The results of the ambient air sample can be utilized to evaluate the influence of outside air on the IA quality. This provision is particularly important for urban settings due to the industrial and automotive

emissions typical of larger cities. In general, mitigation will not be required when the site-specific ambient air results are in excess of the IA results. In these cases, the validity of the ambient air results should be assessed.

The Department's Air Toxics Program measures a suite of toxic VOC, semi-volatile compounds and metals at four monitoring sites – Camden, Elizabeth, Chester and New Brunswick. These four sites in the Air Toxics Monitoring Network provide information on the spatial variation of air toxic concentrations in the state. Further information can be found at <http://www.njaqinow.net/Default.aspx>.

While data from the NJ Air Toxics Monitoring Network cannot replace site-specific results, it does provide a general indicator of potential ambient air concentrations in New Jersey.

4.2.1.4 *Indoor air background databases*

In general, utilization of local, state or regional IA background databases is a primary method for assessing background pollution. The Department has conducted a literature review to determine available information regarding ambient levels of VOC in buildings (Appendix G).

Much of this information was drawn from studies that utilized dedicated IA sampling where measurements were taken at a fixed indoor location. This literature review focuses on studies that have been conducted from the late 1990s to the present.

From the Department's perspective, the most critical study in this literature review is the Department's Indoor Air Background Contaminant Study. One hundred homes were sampled in this study, scattered across 13 primarily suburban and rural counties in the state (Weisel, et al. 2008; Weisel 2006). The homes were single family or semi attached buildings. Almost all of the sampling was conducted in 2004 and 2005, in all seasons. The data from this study represent typical background concentrations in IA specifically related to New Jersey, and were frequently similar to data from the other studies.

Thus, the median concentrations from the New Jersey study were frequently selected as representative values. These representative median IA concentrations (from Table G-4 in Appendix G) can be utilized as a line of evidence in evaluating the analytical results. At no time, however, shall the ambient air results or the representative median IA concentrations be "subtracted" from the analytical results to determine an exceedance of the screening levels.

4.2.2 Secondary Factors

The secondary factors for assessing the VI pathway are provided below.

4.2.2.1 *Building survey*

The investigator should use the *Indoor Air Building Survey and Sampling Form* (Appendix D) when collecting SSSG and IA samples. This questionnaire covers numerous issues, including building characteristics, indoor pollutant sources, miscellaneous items (such as "do you smoke or dry clean clothes?"), sampling information and weather conditions.

When the questionnaire is completed in advance of the IA sampling event and as part of the building walkthrough, potential background sources can be identified and removed/eliminated prior to sampling.

4.2.2.2 *Exterior soil gas sampling*

Department experience has shown exterior soil gas sampling to be an effective screening tool when selecting monitor well locations for ground water delineation of contaminant plumes. However, its success in VI investigations has been suspect. Concerns over false negative results have limited the use of exterior soil gas sampling in determining the presence/absence of a VI problem affecting IA quality. Exterior soil gas sampling may be appropriate, though, when differentiating VI from background sources as part of an IA sampling event.

4.2.2.3 *Building Characteristics*

It is important to understand the building where samples are being collected. HVAC systems that generate positive air pressure can reasonably be expected to prevent or minimize VI within the building. Conversely, a dirt floor or poorly vented crawlspace instead of a concrete slab (or an elevator pit) may significantly increase contaminant concentrations within the building above levels normally calculated using attenuation factors or the J&E model.

Vast differences in building ventilation rates (and thus the intrusion and dilution of vapors from the subsurface) can influence the relative risk to people. Pressure and ventilation testing can provide valuable information, whether the investigator is using a simple smoke stick or electromagnetic flow meters. The age, construction and use of a building are also vital information.

4.2.2.4 *Soil Properties*

Contaminated soil gas moves through the vadose zone by the physical process of diffusion. Soil properties, however, can influence the diffusive movement of vapors. Thus, it is valuable to understand soil stratigraphy, porosity and moisture content, permeability and/ or particle size distribution. Saturated soils from recent precipitation will affect soil gas movement, particularly outside the footprint of a building. These factors in turn influence advection of vapors into a building and the results of IA samples.

4.2.3 Other Lines of Evidence

Other lines of evidence that can play a role in the evaluation of the VI pathway include, but are not limited to, the following:

- site-specific attenuation factors based on radon testing
- soil pump tests (e.g., permeability of soil to air)
- meteorological conditions (e.g., barometric pressure, precipitation)
- building-specific parameters (e.g., pressure testing, ventilation rates)

- vertical profiles of oxygen, carbon dioxide, etc.
- constituent ratios in soil gas/IA results
- presence of preferential pathways
- temporal and spatial variability in concentrations
- changes in the height of the water table
- modeling
- influence of on-going remedial actions

Use these MLE to verify the CSM developed at the outset of the VI investigation. Refer to Section 2.4.4 for a discussion on data deliverables and usability and Section 2.4.5 for the role of the Department's Technical Consultation with the use of these lines of evidence. The investigator should consider that mitigation can be implemented at any time during a VI investigation.

4.3 Data Evaluation

4.3.1 Background Sources

One of the most critical steps during a VI investigation is the evaluation of analytical data, particularly as it relates to source identification. Due to the fact that the human health-based standards for IA quality are low, the potential for confounding background sources in buildings can be a significant factor in decision making. Refer to Appendix H, *Common Background Indoor Air Sources*, for additional information. Therefore, include an assessment of potential background sources in any data evaluation process. As a general point, mitigation will not be required when the site-specific ambient air results are in excess of IA results.

4.3.2 Ground Water Samples

Evaluate the ground water data to determine whether the contaminant plume has been delineated to the extent needed to assess the VI pathway. If the plume has not been sufficiently delineated, additional ground water samples will be required to complete the delineation as it pertains to this pathway.

Assuming the samples are collected consistent with the procedures and recommendations in Section 3.2 of this technical guidance and the Department's FSPM, compare the data that are representative of site ground water conditions to the Department's GWSL. An exceedance of these screening levels for any compound will necessitate further investigation. However, it should not be assumed that elevated ground water concentrations automatically indicate that unacceptable levels of vapors are currently entering the building.

Investigate all existing buildings that are located within the critical distance criteria of the shallow plume's perimeter. If preferential pathways (anthropogenic or natural) or a landfill are nearby, the investigator should consider whether the critical distance criteria are adequately protective. The results of this effort will highlight those buildings that will necessitate further investigation for the VI pathway.

4.3.3 Multi-Depth Ground Water Contaminant Data

At sites where ground water data from multiple depth intervals are available, vertical profiles of volatile levels in ground water or data from well pairs/clusters, etc. may reveal various patterns that are likely to have different implications for the current and future risk of VI. The following guidelines should be used to interpret the data.

When vertical profiling is done, a **six-foot thick lens** of ground water, measured from the surface of the water table to the contaminated plume, with contaminants below the Department or approved site-specific GWSL, can be considered sufficient justification to conclude the plume is not a source for VI in the immediate vicinity. When multi-depth monitoring well pairs or clusters are used and ground water in the top 6 to 10 feet of the saturated zone is below the GWSL, the same conclusion is appropriate. In both of these situations, additional ground water sampling for a VI investigation should not be required unless conditions change, or are expected to change to include any circumstances that will cause the water table elevation to decrease significantly. However, ongoing evaluation and monitoring of VI risks are part of an approved remedial action, VI receptor evaluation, and ground water CEA.

If a **lens between three and six-feet thick**, not exceeding the GWSL, exists between the vadose zone and the part of the plume that does exceed GWSL, significant off gassing into the vadose zone is unlikely. However, in this situation, ongoing periodic water level and/or ground water monitoring should be performed to confirm the continuing presence of a “below GWSL lens” of at least 3 feet in thickness. If water level data or other information strongly suggest that a below GWSL lens at least 3 feet thick is not present throughout the year, additional investigation of the VI pathway (soil gas and/or IA sampling) should be conducted.

A below GWSL **lens less than three-feet thick** overlying a plume which exceeds the GWSL should trigger additional investigation of the VI pathway and possibly ongoing ground water monitoring. Conditions which should be considered in designing the next investigative step include types of contaminants present; concentrations of contaminants in the various depth intervals sampled; and thickness of the below GWSL lens in the multi-depth sampling location nearest to the building.

4.3.4 Sub-Slab Soil Gas Samples

Compare the analytical results of the SSSG samples to the Department’s SGSL. If the soil gas results exceed the Department’s SGSL, additional investigation of the VI pathway is necessary. Unless the investigator is proposing a site-specific approach, IA sampling will be necessary.

In those situations where the soil gas results do not exceed the Department’s SGSL but ground water quality exceeds the Department’s GWSL by greater than 10X, the investigator should consider additional soil gas investigation (based on professional judgment) to confirm the initial findings. At that point, a site-specific determination can be made on the need for additional VI investigation. Base this determination on an accurate CSM and representative ground water data which indicate:

- shallow ground water concentrations are unlikely to increase in the future; and
- other site conditions at the time of sampling (e.g., soil moisture, percentage oxygen in vadose zone) are unlikely to change enough to result in higher soil gas levels.

Based on the sampling plan, the number of SSSG samples may have to be increased to address spatial variability. The results of the SSSG samples should not be averaged across the subsurface of a building. Therefore, each data point should be evaluated independently of each other.

The compounds detected in the sub-slab (or near slab/exterior, when appropriate) soil gas results should be compared with the site-specific COCs (including degradation products) identified from the contaminated ground water or soil. If additional and/or unrelated compounds are seen in the soil gas results, a secondary VI source may be present. A supplemental investigation of the on-site soils, ground water or building parameters may be warranted.

4.3.5 Indoor Air Samples from the Basement

The analytical results of the IA samples from a basement shall be compared to the Department's IASL (N.J.A.C. 7:26E-1.18).

If the IA results exceed the applicable Department's IASL, the investigator shall follow the Technical Rules for VC or IEC (N.J.A.C. 7:26E-1.18 and 1.14, respectively). Additional information on mitigation can be found in Chapter 6.

Multiple samples collected from different locations on the same floor may identify probable background sources when combined with a building walkthrough and survey. Compare the locations of suspect consumer products (e.g., paints, thinners) or household activities (e.g., hobbies, smoking) with the IA sample results. Evaluate whether particular volatile compounds are higher or lower in certain portions of a building and if they correlate with identified background sources. Additionally, determine if the site-specific COCs compare to the IA compounds detected in the sample results. The need to collect multiple IA samples from the same level is left to the investigator's professional judgment and a review of the CSM based on the likelihood of significant background sources or building-specific parameters.

In addition, compare the analytical results with potential vapor entryways through the building slab or foundation (e.g., sumps, drains, utility lines, major cracks, elevator pits). Depending on the ventilation system in the basement, differences in concentrations of site-specific COCs between multiple sample points may be related to their relative position near vapor entryways, and not background sources.

4.3.6 Multiple Indoor Air Samples from Different Floors

If the investigator elects (based on professional judgment) to collect IA samples from at least two separate floors within a building, the basement (or lowest floor) and the level immediately above it are recommended. This is important in situations where SSSG samples are not collected. In part, the rationale for this approach is to provide the investigator with analytical results that may assist in the assessment of potential background contaminant sources.

Compare the results for individual compounds on each floor. In general, the concentrations should decrease with distance from the source. Thus, if VI from contaminated ground water or subsurface soil is the main source, the highest concentrations should be in the basement (or lowest floor) and decrease in samples collected from the floors above. Conversely, if the higher concentrations are found in the upper floors (when compared to the basement results), a background source unrelated to the site is probably located within the building on the floor with the highest concentrations. Divergence from this general understanding of vapor movement may exist in situations where a vertical pathway allows vapors to move quickly from one floor to the next (e.g., elevator shafts, laundry chutes).

The first step in differentiating background contamination during IA sampling events is to identify the site-specific COCs (based on ground water or subsurface soil data). When these COCs are found in potential background sources located within the building under investigation, results from multiple IA samples can be compared to the relative concentrations of related contaminants.

For example, BTEX are common contaminants associated with gasoline. Compare the concentrations of each of these contaminants relative to each other. Evaluate whether a similar relationship exists between the contaminants detected in other samples collected either on the same or different floors of the building. If benzene and toluene generally have a 1:1 ratio in the basement and the second floor samples have three times as much toluene as benzene, it is probable that a secondary background source of toluene is located on the second floor (e.g., nail polish).

4.3.7 Indoor Air and Sub-Slab Soil Gas Samples

The combination of IA and SSSG results will assist in identifying likely background IA sources and verify whether a VI source exists below the building (instead of extrapolating contaminated ground water or subsurface soil results from IA).

The Mitigation Decision Matrix (part of the *Decision Flow Chart - Appendix A*) is designed to assist the investigator in assessing the VI pathway. Specifically, the Mitigation Decision Matrix evaluates the relationship between the SSSG and IA sample results, providing technical guidance on the appropriate action (e.g., no action, monitoring, and mitigation).

Frequently, contaminants will be found in the IA, but not the SSSG samples. The compounds are likely originating from background sources unrelated to VI (especially if they are not site-specific COCs). In these cases, the Mitigation Decision Matrix directs the investigator to evaluate vadose zone (soil) contamination and preferential pathways as potential contributors to IA contamination that might not be detected in the subsurface soil gas results. Once it is established that VI is not contributing to the IA contamination, and will not in the future, no further action is necessary for this pathway.

The investigator will identify cases where the IA concentrations are below the IASL, but the SSSG results are elevated, indicating a potential source in the subsurface. In these situations, the

Mitigation Decision Matrix differentiates between elevated SSSG results that are less than or more than 10 times the SGSL.

For SSSG results that are greater than the SGSL but at or less than 10 times the SGSL, long-term monitoring (LTM) is recommended. LTM provisions are outlined in Table 6-3. If the IA results collected during the LTM exceed the IASL and the results are linked to a completed VI pathway, the Technical Rules require appropriate mitigation [N.J.A.C. 7:26E-1.18(c)].

When the SSSG results are greater than 10 times the SGSL, the investigator should use professional judgment to determine whether LTM or mitigation is appropriate. The Mitigation Decision Matrix includes mitigation in this scenario due to the increased likelihood that VI will occur in the future if the source of the high soil gas concentrations is not addressed.

The clearest picture of the contribution of background IA sources, though, is observed when SSSG results are combined with IA data collected from different floors or various locations on each floor.

As an example, Table 4-1 below presents a summary of soil gas and IA results collected during an investigation of a gasoline plume in the coastal plains of New Jersey. Even though free product was found adjacent to the building, numerous gasoline-related compounds were not detected in the SSSG samples, probably due to aerobic biodegradation in the vadose zone. Other gasoline related compounds, namely methyl tertiary-butyl ether (MTBE) and 2, 2, 4-trimethylpentane, were detected at high concentrations in the SSSG and at decreasing levels in the basement and first floor. These data strongly supported the assumption that the VI pathway was complete. Thus, mitigation is necessary (consistent with the Mitigation Decision Matrix) to address the VI pathway.

Table 4-1
Illustrative Example of Sub-Slab Soil Gas and Indoor Air Results

Chemical	Soil Gas Results	IA Results	IA Results
	Sub-slab	Basement	1st Floor
Benzene	ND (16)	ND (2)	ND (2)
Cyclohexane	15,000 (310,000)	120 (6,200)	25 (6,200)
Ethylbenzene	ND (53,000)	ND (1,100)	10 (1,100)
4-Ethyltoluene	ND (---)	ND (---)	19 (---)
Methylene chloride	ND (190)	ND (4)	100 (4)
MTBE	18,000 (78)	140 (2)	50 (2)
Toluene	ND (260,000)	ND (5,100)	45 5,100)
2,2,4- Trimethylpentane	93,000 (---)	700 (---)	160 (---)
Xylenes (<i>m & p</i>)	ND (5,500 total)	14 (110 total)	39 (110 total)
Xylenes (<i>o</i>)	ND (5,500 total)	ND (110 total)	17 (110 total)

Results in $\mu\text{g}/\text{m}^3$

Current Screening Levels in parentheses

ND - non-detect

There were, however, contaminants present in the basement or first floor IA samples and not in the SSSG. Had MTBE not been present, the Mitigation Decision Matrix would recommend no further action. A review of the building survey form in this particular case revealed that the occupants utilized various solvents as part of their operations, including methylene chloride, toluene and xylenes. These IA contaminants originated from background sources and should not be factored into mitigation related to site contaminants. For an example of how MLE are applied in the determination of VI, consult Sanders & Hers (2006).

4.4 Compliance

As discussed in Section 2.2.3, IA analytical results are compared to the IASL and the RAL. An IEC is present when VI related IA concentrations exceed the RAL, the source of the COCs is due to a discharge, and a completed pathway for VI has been confirmed. Additional actions are required to mitigate the VI pathway (N.J.A.C.7:26E-1.14).

If VI related IA concentrations exceed the IASL, but are equal to or less than the RAL, a VC exists (N.J.A.C.7:26E-1.18). Additional actions shall include the development of a VC Mitigation Plan to address impacts to the IA quality of the building. Refer to Appendix B, *Vapor Intrusion Timeline*, for additional information on specific forms and deliverable requirements and related timeframes.

HDNL were developed in consultation with the NJDHSS. These values, when exceeded in occupied buildings, represent levels that trigger the investigator to contact the NJDEP, NJDHSS and the local health department by telephone regarding the levels detected. The local health department or NJDHSS would then have the information necessary to make a decision regarding the need for any emergency actions, such as the evacuation of an occupied building.

The NJDEP shall be contacted if the driver chemical at a site does not currently have an RAL or HDNL value to identify an applicable level (N.J.A.C. 7:26E-1.14(b)5).

4.5 Official Notification

Building owners, tenants, and occupants shall be notified about their IA and/or soil gas analytical results whenever samples are collected (N.J.A.C. 7:26E-1.18). This is the responsibility of the investigator.

The written reports should consist of a cover letter explaining the findings and a table summarizing the analytical results.

In cases where the compounds in excess of IASLs are concluded to be originating from background sources unrelated to VI, the occupants should be directed to consult with the local health department on ways to reduce background sources. Check the NJDEP VI website at <http://www.nj.gov/dep/srp/guidance/vaporintrusion/> for generic VI results notification letters and summary tables.

5.0 PETROLEUM HYDROCARBONS

5.1 Introduction

As defined in the Underground Storage of Hazardous Substances Rules (N.J.A.C. 7:14B):

petroleum or petroleum products means all hydrocarbons which are liquid at one atmosphere pressure (760 millimeters or 29.92 inches Hg) and temperatures between -20°F and 120° F (-29° C and 49° C), and all hydrocarbons which are discharged in a liquid state at or nearly at atmospheric pressure at temperatures in excess of 120° F (49° C) including, but not limited to, gasoline, kerosene, fuel oil, oil sludge, oil refuse, oil mixed with other wastes, crude oil, and purified hydrocarbons that have been refined, re-refined, or otherwise processed for the purpose of being burned as a fuel to produce heat or useable energy or which is suitable for use as a motor fuel or lubricant in the operation or maintenance of an engine.

Hydrocarbons as a whole consist of hundreds of chemical compounds that range through volatile, semi-volatile and nonvolatile organic fractions.

The Department considers a chemical to be a source of VI if it has sufficient volatility and toxicity in the subsurface with sufficient mass or concentrations to pose a possible inhalation risk within overlying buildings. When comparing the two definitions, it is apparent not all petroleum related chemical compounds represent a VI risk. The primary VI risks are associated with the PHC compounds that make up the lighter (shorter carbon chain) petroleum fractions, such as gasoline, diesel fuel, No. 2 heating oil, kerosene and aviation fuel.

5.2 Biodegradation

It has been well documented that petroleum-related hydrocarbon chemicals typically undergo aerobic biodegradation in the unsaturated soil zone (Roggemans et al. 2001, Lahvis et al. 1999, Devaull et al. 1997). While earlier evidence suggested that a soil oxygen level above 4% was needed for biodegradation to occur (DeVaull et al. 1997), evidence that is more recent suggests that the threshold concentration may be lower, between 1-2% (Roggemans et al. 2001, Abreu et al. 2009).

Because the GWSLs are calculated using the J&E spreadsheets that doesn't incorporate contaminant degradation, the Department, as well as several other state environmental agencies, applies an additional attenuation factor to the calculated screening levels to account for this process. Values for the degradation attenuation factor are dependent on the distance between the contamination and the building of interest, the biodegradation rate, the vapor source concentration and the supply of oxygen (Golder Associates 2008; Abreu et al. 2009).

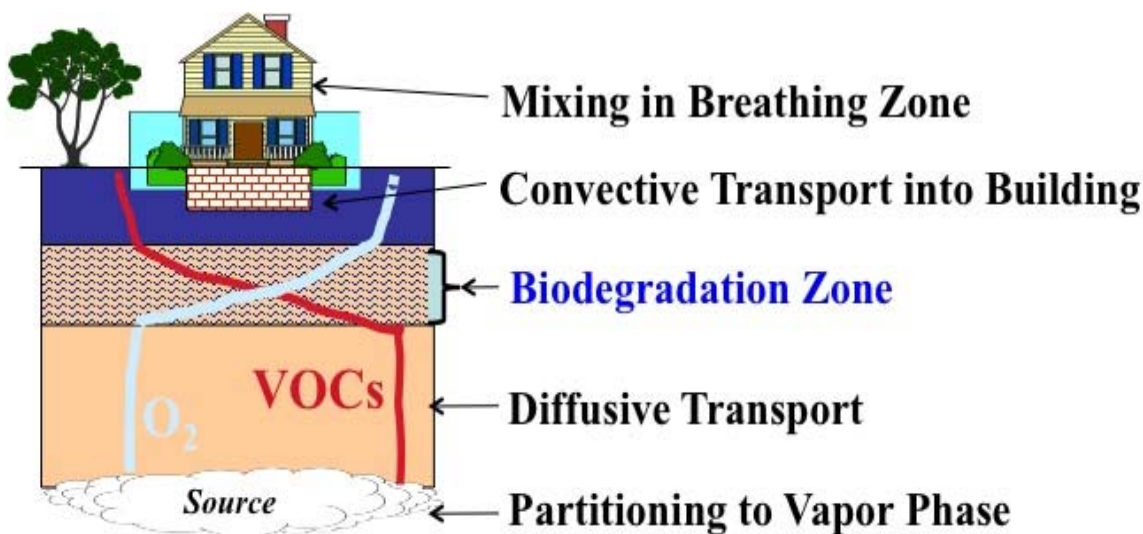


Figure 5-1
Petroleum VI Conceptual Site Model (courtesy Geosyntec Consultants)

Under actual field conditions, the magnitude of the attenuation factor is highly variable, depending on the availability of oxygen in the soil and other soil and environmental conditions. However, recent recommendations from the literature suggest that an additional attenuation factor of at least 0.1 is appropriate under most environmental conditions and at most VI sites. An attenuation factor of 0.1 was therefore incorporated into the default GWSL for petroleum-related compounds (e.g., BTEX). Oxygenated chemicals (e.g., MTBE) degrade more slowly (Squillace, et al. 1997). Thus, the factor was not used for these chemicals.

As noted in Section 2.4.3 and consistent with USEPA, the VI pathway warrants investigation when a building is “located within 100 feet laterally or vertically of known or interpolated soil gas or ground water contaminants...and the contamination occurs in the unsaturated zone and/or the uppermost saturated zone.” (USEPA 2002b) The 100-foot horizontal or vertical critical distance criterion for investigating the VI pathway does not consider the degradability of the PHC compounds. As such, the Department utilizes a 30-foot horizontal and vertical critical distance criterion for all petroleum related contamination provided non-aqueous phase product is not present. With non-aqueous phase PHCs, the critical distance criterion is 100 feet horizontally or vertically of a building.

Specific gasoline exclusion criteria are discussed below.

5.3 VI Investigation

When a petroleum discharge occurs and a ground water site investigation is triggered, an evaluation of the VI risk to receptors must proceed concurrently by comparing the ground water results to the NJDEP GWSLs for VI. Based on N.J.A.C. 7:26E-1.18, an evaluation of the VI pathway is necessary if NAPL is located, or suspected, within 100 feet of a building, or petroleum related contaminants are present in the dissolved phase in excess of the GWSL within 30 feet of a building.

For active gasoline service stations, IA samples should not be collected from site-related buildings due to the difficulty in determining whether air contaminants are from operational activities associated with the facility or from VI. However, SSSG sampling should be conducted to take into consideration any future changes in use for the property. If sub-slab results exceed the SGSL, the MME plan for the applicable institutional control (e.g., a CEA) should require additional VI investigation if the property use changes. Alternatively, an institutional control can be voluntarily placed on the property that would delay the initial sub-slab sampling until the remediation is completed or the site use changes. See Section 6.4.1 for more information regarding institutional controls and the MME plan.

5.4 Alternative Approaches

Recent analyses of field databases have shown significant biodegradation of petroleum compounds under aerobic conditions (Hartman, 2010) suggesting that an alternative approach to assessing PHCs for the VI pathway may be appropriate. Accordingly, this technical guidance provides optional investigative methodologies for PHCs that the investigator may employ. While these alternative investigative approaches are not considered a technical variance or site-specific alternate screening criteria, the investigator is obligated to properly document the appropriateness of employing this approach and the supporting analytical and technical data. Provide this information in the next submission to the Department.

5.4.1 Gasoline Discharges

Gasoline discharges constitute a significant portion of the petroleum-related VI investigations in New Jersey. Thus, specific exclusion criteria have been developed for gasoline discharges only. To employ the gasoline exclusion criteria, the four conditions listed in Section 5.4.1.2 should be met.

5.4.1.1 Gasoline Exclusion Criteria

With a gasoline discharge, benzene serves as the exclusive VI trigger. A VI investigation is not necessary if any one of the following scenarios exists and all of the conditions outlined in 5.4.1.2 are met:

- a. the vertical separation distance between the seasonal high water table and the building slab is estimated (using available data) to be at least 10 feet, and benzene concentrations in the shallow ground water under the building are estimated to be 1,000 µg/L or less;
- b. the vertical separation distance between the seasonal high water table and the building slab is estimated (using available data) to be at least 5 feet and benzene concentrations in the shallow ground water under the building are estimated to be 100 µg/L or less; or,
- c. the vertical separation distance between the seasonal high water table and the building slab is estimated (using available data) to be at least 5 feet, the presence of $\geq 2\%$ (v/v) oxygen in the vadose zone is measured at the appropriate location (see Section 5.4.1.3), and benzene concentrations in the shallow ground water under the building are estimated to be 1,000 µg/L or less.

When the vertical separation distance between the water table and the building is less than 5 feet, NO CHANGE in the screening criteria is proposed, because the criteria were calculated assuming a 5-foot separation distance, and they already incorporate a 10x biodegradation factor for select PHCs.

5.4.1.2 Conditions for Application of Gasoline Exclusion Criteria

The gasoline exclusion criteria apply only when all of the following four conditions exist (using professional judgment):

- 1) the building is detached and relatively small (e.g., a single family home, fast food restaurant or duplex home);
- 2) the area around the building is not extensively paved;
- 3) clean soil exists between the water table and the building slab (no source of contamination in the vadose zone is likely); and
- 4) NAPL is not present within 30 feet of the building (vertically and horizontally).

The purpose of the conditions is to exclude buildings where the potential for an area of depleted oxygen exists under the building. This is common with larger warehouses, box stores and office complexes.

5.4.1.3 Collecting O₂, CO₂, CH₄ for Application of Gasoline Exclusion Criteria

In general, the investigator may want to utilize fixed gas detectors to establish the subsurface concentrations of O₂, CO₂, CH₄ and other gases as a line of evidence, particularly for petroleum hydrocarbons. A vertical profile of these gases can assist with documenting biodegradable conditions.

Fixed gas detectors can be utilized in combination with near slab sampling by following the provisions in Section 3.3.2 and the sampling specifications outlined below (in order of priority):

- within 10' horizontally of the building of concern;
- on the side of the building estimated to have the highest contaminant concentrations in the underlying ground water;
- at a depth midway between the building slab and the water table, or deeper; and
- at least five feet below the ground surface.

These specifications are given to minimize “edge effects” observed when sampling is not conducted directly under a building.

5.4.2 Discharges of No. 2 Fuel Oil / Diesel Fuel Oil & Heavier Petroleum Fractions

Based on Department policy, a VI investigation is not required at a site solely based on a discharge of No. 2 fuel oil and/or diesel fuel. As such, the provision at N.J.A.C. 7:26E-1.18(a)3 does not apply for discharges of No. 2 fuel oil and/or diesel fuel. However, the presence of No. 2 fuel oil and/or diesel fuel on the water table or within the unsaturated zone will necessitate the collection and analysis of a ground water sample pursuant to the N.J.A.C. 7:26E-2.1(d). A VI

investigation is required if any ground water sample collected within 30 feet of a building contains a contaminant in excess of any VI GWSL (N.J.A.C. 7:26E-1.18(a)1). In addition, a VI investigation is required if any of the conditions listed in the Technical Rules at N.J.A.C. 7:26E-1.18(a)4 are met.

If all Number 2 fuel oil and/or diesel fuel oil free product at a site will be excavated or otherwise removed within 6 months after detection, ground water sampling to evaluate VI could be postponed until immediately after such remedial actions are completed (based on professional judgment). This would be the situation for VI investigations for discharges from many unregulated heating oil tank (UHOT) sites.

If Number 2 fuel oil and/or diesel fuel oil free product is on the water table (or in soils) within 30 feet of a building and it is not removed within 6 months after it is detected, the collection of ground water sampling as part of the VI investigation should proceed. The investigator can opt to move directly to SSSG sampling when obtaining a ground water sample if the needed location is a challenge due to the presence of product on the water table. Alternatively, various ground water sampling options are discussed in the NJDEP FSPM and on the Department's VI website, <http://www.nj.gov/dep/srp/guidance/vaporintrusion/>.

The presence of petroleum odors in a building is not a trigger to conduct a VI investigation. Rather, the presence of such odors should be used as an indication of a possible discharge and the presence of free product in soil that should be investigated. Subsequent investigation could lead to a VI investigation.

N.J.A.C. 7:26E-2.1(d) requires semi-volatile organic analysis of ground water samples for heavier (longer carbon chain) petroleum fractions, including kerosene, jet fuel, No. 2 fuel oil, diesel fuel, No. 4 and 6 fuel oils, hydraulic oils, cutting oil, lubricating, and crude oil. As it relates to a VI trigger, the investigator should evaluate the ground water results for 2-methyl naphthalene and naphthalene as the exclusive target compounds, in addition to benzene.

6.0 VAPOR INTRUSION MITIGATION

VI mitigation techniques should be evaluated when it is determined that the VI pathway is complete. The objective of vapor mitigation is to interrupt the pathway between the source (contaminated ground water and/or subsurface soils) and the receptors (building occupants). Ultimately, the primary goal is to remediate the source of the vapor contamination (ground water and/or subsurface soil) such that the risk of VI contaminant levels harmful to humans is eliminated. Thus, mitigation of the VI pathway through building control remedies is considered an ESRA pending the final remediation of the contaminant source.

This section focuses on the various vapor mitigation options appropriate for VI and the OMM provisions associated with these techniques. Due to the similarities between VI related to volatile contaminants and radon, many of the mitigation techniques discussed below originate from guidance documents addressing radon mitigation.

6.1 Initial Response Actions – Overview and Timeframes

The mitigation and reporting of VI shall follow regulatory timeframes related to the type of vapor exposure. These timeframes vary based on the levels of IA contaminant concentrations that will require an emergency response, IEC or VC action. The response action timeframes are defined in the following sections and summarized in Appendix B.

The investigation and mitigation of the VI pathway is an iterative process. At larger sites, buildings may be undergoing mitigation while others are subject to the early stages of investigation. Thus, the investigator should always be aware of the appropriate actions for any given building and at any given time.

6.1.1 Response Action Categories

6.1.1.1 *Immediate Environmental Concern*

When an IEC is identified in a building that is related to the site under investigation there are mitigation responses that must be completed within a required timeframe set in N.J.A.C. 7:26E-1.14. These include IRA and the ESRA. Additional technical guidance for VI IEC is included in the Department's Immediate Environmental Concern Technical Guidance, 2011 (<http://www.nj.gov/dep/srp/guidance>). The required mitigation actions are further defined in the following sections.

6.1.1.2 *Vapor Concern*

If a condition in a building has been identified as a VC, the investigator has longer timeframes to complete the mitigation than for an IEC due to the lower exposure levels. The required timeframe for mitigation responses in a VC case are set in N.J.A.C. 7:26E-1.18. The investigator also has the option to implement an IRA in VC cases. This action is the same used for an IEC IRA (Section 6.1.2.2).

6.1.1.3 Emergency Response Action

For VI cases, an emergency response action is not the same as an IEC. In rare instances, VI conditions may cause toxic or harmful sub-surface contaminants to have migrated into an occupied or confined space in a building, producing a toxic atmosphere that is immediately dangerous to life and health due to an oxygen deficient atmosphere, or results in the collection of explosive gasses. Explosive gasses are defined as levels that exceed 10 percent of the lower explosive limit (10% LEL) for that compound. In these cases, the investigator shall immediately notify emergency responders and the Department upon knowledge of the results/measurements (N.J.A.C. 7:26E 1.18). After the emergency condition has been mitigated, further response and reporting requirements should follow the Technical Rules.

6.1.1.4 VI Contamination Unrelated to Site Being Investigated

As previously stated, contamination detected in soil gas and/or IA that is not a COC or is unrelated to the site undergoing investigation shall be reported to the Department. The Department's Publicly Funded program will pursue VI sampling at buildings (residential and nonresidential) where the contaminant exceeds the applicable VI screening level, is from an unknown source and is not a COC under investigation.

6.1.2 Specific Response Actions

The required response actions and their timeframes can vary based on the level of vapor exposure. A description of the required response actions is provided in the following sections. Additional information may be found in Appendix B.

6.1.2.1 Department Notification

For an IEC, the investigator must notify the Department immediately upon knowledge (receipt of data) of the IEC (N.J.A.C.7:26E-1.14(b)1) by calling the assigned Site Remediation Program case manager, or if one is not available or assigned, then call the Department Hotline (1-877 WARNDEP). When contacting the DEP Hotline, the caller shall notify the operator that the project is an "IEC Case." The Department will assign an IEC case manager who will contact the investigator.

For VC cases, the investigator must notify the Department within 14 days upon knowledge (receipt of data) of the VC condition by submitting a completed Vapor Concern Response Action Form (<http://www.nj.gov/dep/srp/srra/forms>) to the case manager or the Bureau of Case Assignment and Initial Notice (N.J.A.C.7:26E – 1.18(f)1i).

6.1.2.2 Interim Response Action (IRA)

If an IEC has been discovered for a building, the investigator shall take IRAs to protect the health of people in the building prior to the installation and startup of the ESRA. The IEC IRA shall be implemented within 14 days after the date of discovery of the IEC (N.J.A.C. 7:26E-1.14(b)2). Refer to the Department's Immediate Environmental Concern Technical Guidance document for additional submittals and forms required within the 14 day period. Due to the time

critical actions stipulated for the IRA, the Department does not require a formal plan. Documentation detailing the IRA is required to be electronically submitted to the Department.

For a VC, the IRA is optional but is recommended to reduce the exposure of contaminants to occupants in a building. Typical IRAs for IEC or VC cases may include the following:

- sealing major openings and cracks with caulk or expanding foam (volatile-free);
- repairing compromised areas of the slab;
- covering and sealing exposed earth ;
- covering and sealing sump pits;
- utilizing IA treatment such as carbon air filtration fan units ;
- implementing selective ventilation (based on the neutral pressure plane) particularly for basements and crawl spaces;
- balancing of air handling systems (HVAC) or use of dynamic building controls to create positive room/building pressure;
- enhancing natural ventilation of the building;
- limiting access to the building or area of impact; and
- remove occupants from the building.

The appropriate IRA for each building will vary based on numerous issues (building construction, vapor entryways, etc.).

It is recommended that field analytical methods be employed to aid in the possible locations of entranceways or “hot spots” for VI and to possibly further define the scope of the work for the IRA or ESRA. In addition, field analytical methods can be used to aid in the assessment of the effectiveness of the IRA and used in diagnostic testing for the implementation of the engineered response action with the benefit of instantaneous results.

In some cases the implementation of the IRA may mitigate VI. The IRA actions must be permanent, and the success of the IRA to mitigate VI should be determined by IA sampling. If unsuccessful, compliance with the timeframes to implement the ESRA is still required.

6.1.2.3 VC Mitigation Plan

A VC Mitigation Plan shall be submitted to the Department within 60 days from the receipt of the data package showing the VC condition. The Plan should be a brief overview of the actions proposed to mitigate the VI pathway and eliminate the receptor exposure. The plan should include:

- identification of the property/building with municipal lot and block numbers
- description and technical justification for the mitigation proposed
- submission of all relevant data (to date) and appropriate spreadsheets/forms
- post-mitigation sampling plan to confirm the success of the mitigation
- operation, maintenance and monitoring plan

If an IRA is implemented for a VC case, documentation describing the IRA should be included in the VC mitigation plan.

Department approval of the VC mitigation plan is not required prior to implementation of the ESRA unless an alternative VI methodology is proposed for a site covered under the Presumptive and Alternative Remedy requirements (N.J.A.C. 7:26E-5.1(i)).

6.1.2.4 *Engineered System Response Action (ESRA)*

An ESRA is a vapor mitigation system that is installed to control receptor exposure. Within 60 days after the discovery of an IEC, the investigator shall implement (i.e., complete, operating) an ESRA to mitigate the entry of vapors into the building (N.J.A.C. 7:26E-1.14(b)5). For a VC, an ESRA must be implemented within 120 days from the time of discovery (N.J.A.C. 7:26E-1.18(f)1iii). The ESRA should be completed in accordance with the Department's Presumptive and Alternative Remedy Technical Guidance, 2011 (<http://www.nj.gov/dep/srp/guidance/>), if applicable.

To document the mitigation action for an IEC, an ESRA report shall be submitted to the Department within 120 days after identifying the IEC (N.J.A.C. 7:26E-1.14(c)). For VCs, a VC mitigation response action report shall be submitted to the Department within 180 days from the time of discovery (N.J.A.C. 7:26E-1.18(f)1iv). The required information that should be included in the report is found in the Department's NJDEP Immediate Environmental Concern Technical Guidance and Section 6.4.4 of this document. Appendix B summarizes the response action timeframes for IECs and VCs.

6.2 **Mitigation Methods**

There are numerous approaches to building control remedies for the VI pathway based primarily on the building construction (e.g., existing, slab-on-grade, basement, crawl space). These vapor control technologies involve preventing infiltration of subsurface vapors into a building by application of a barrier, sub-slab venting and/or adjustments to the pressure differential between the subsurface and the interior of the building.

The type of vapor mitigation system installed will be determined by factors such as the use, construction and design of the building, the sub-slab soils and, whether the building is existing or new. Also, the applicability of the presumptive remedy requirements (N.J.A.C. 7:26E-5.1(i)) for any remediation initiated after May 7, 2010 will affect the mitigation selection. A presumptive remedy at a VI site is a mitigation action that can be implemented at a site without the need for Department approval. For the new construction of schools, child care facilities and residential buildings, a passive subsurface depressurization system that can be readily upgraded to an active system is the presumptive remedy. An active subsurface depressurization system in this scenario is an alternative mitigation methodology.

For existing buildings, an active subsurface depressurization system is the preferred method. However, the investigator may modify the mitigation technique based on the results of a VI investigation and communications testing (Section 6.3.2).

6.2.1 Active Subsurface Depressurization Systems

The objective of an active subsurface depressurization system is to apply a negative pressure field or vacuum beneath and/or around the building of concern, thereby preventing VI into the building. Active subsurface depressurization systems utilize a fan or blower to create a continuous negative pressure field (vacuum) below the slab. While subsurface depressurization systems can be either passive or active, the preferred approach is the active system due to its higher success rate in mitigating VI in existing buildings.

Active subsurface depressurization systems are designed to prohibit the movement of volatile contaminants into a building from the soil zone directly around a building. The Department, however, does not consider this action to separately constitute a remedial action of the site contaminants found in soil or ground water. These systems, as well as their ongoing OMM are, however, considered part of the remedial action for the site. The volume of contaminants removed by the mitigation system is incidental to the overall site remediation and does not address source control. As a result, these systems by themselves are not considered capable of ensuring that contaminants are remediated in compliance with all applicable remediation standards.

Some of the types of active subsurface depressurization systems that may be employed to mitigate VI are as follows:

1. Sub-Slab Depressurization System (SSDS) - When combined with reasonable sealing of significant infiltration points, SSDS is typically the most effective mitigation method for buildings with a basement slab or slab-on-grade foundation (NYSDOH 2006). Concentration reductions of 99.5% or greater have been obtained in carefully designed and installed systems in existing residential buildings (Folkes 2002a).

Depending on the size of the slab and the characteristics of the sub-slab material, piping may have to be installed vertically through the existing slab in multiple locations to create a negative pressure field across the entire sub-slab area. For new construction with highly permeable venting layers, lateral perforated piping and/or barrier membranes are often installed in the subsurface beneath the slab and a fan is used to create a negative pressure field in the sub-slab area and discharge any vapor outside the building.

2. Sub-Membrane Depressurization System (SMDS) – This technique can be used when a building has an earthen (or gravel, etc.) floor or crawlspace, as opposed to, or in addition to a slab. A membrane, such as a high-density polyethylene (HDPE), is used to cover the earthen floor or crawlspace area. Similar to sub-slab depressurization a negative pressure field is created beneath the membrane thereby preventing VI. Properly seal the membrane to the building walls, suction pipe, etc. and kept intact in order to maintain the negative pressure field. The piping that is used to create the negative pressure field beneath the membrane can be configured in various ways. Insert piping vertically through the membrane or perforated piping can be laid horizontally beneath the membrane.

3. Block Wall Depressurization System (BWDS) – Use this technique when a building has a block wall or cinder block foundation. In this scenario, the negative pressure field is created via piping inserted through the voids in the block wall. Seal any openings in the top of the block wall and all openings or cracks on the interior surface of the wall. This technique is typically used in conjunction with one of the other depressurization techniques.
4. Drain Tile Depressurization System (DTDS) – Use this technique when a building has a loop of perforated drain tiles (piping) adjacent to the building footers for water drainage. If the drain tiles discharge to a sump pit, the sump pit is sealed and the negative pressure field is applied to the sump pit.

6.2.2 Passive Subsurface Depressurization Systems

Passive subsurface depressurization systems do not use a fan or blower to move air from the subsurface. They operate by the use of natural phenomena, thermal effects, pressure gradients and wind to develop suction in the stack. Thermal convective flow operates on the differential temperature between the stack and the subsurface. The vent pipe is routed through the warm space in the building, which is a higher temperature than the subsurface, creating a natural upward draft of air in the vent (stack effect) to draw air from beneath the slab. Advective flow occurs due to pressure gradients between the sub-slab atmosphere and the ambient air. Wind creates a low-pressure region as air moves over the roof. This low pressure “pulls” air from the subsurface through the stack.

Passive systems are not recommended in existing buildings due to the lower success rate when compared to active systems. The best application of a passive system is during new building construction or for an existing building when specific site conditions such as the presence of a highly permeable sub-slab material, synthetic venting materials (e.g., geogrids) or aerated floor system (Cupolex) are installed which are amenable for a passive system.

Since a high water table will significantly decrease the efficiency of a passive system, use of passive subsurface depressurization is conditioned upon the seasonal high water table being no closer than 5 feet below the building slab.

A passive subsurface depressurization system should be installed so that it can be easily upgraded to an active system based on the upgrade factors listed in Table 6-2. Passive systems generally include the following major components:

- Venting layer that will allow unimpeded lateral flow of soil gas;
- Lateral perforated piping installed in the venting layer to collect vapors (unless void space technology is employed);
- Passive barrier (membrane) installed above the venting layer, 40-mil HDPE or equivalent (USEPA 2008a);
- Vertical exhaust lines must run through the heated space of the building and discharge above the roof; and.
- Electric service run to each vent pipe in an unoccupied space (attic, etc.) to allow quick conversion to an active system by installing a fan.

Because passive systems can only draw low flows of vapors, any leakage of air into the building through a crawl space, cracks or membrane opening will reduce what is already a weak subsurface vacuum and flow field. Therefore the slab and membrane sealing steps and procedures become even more important in a passive system.

The installation of a wind turbine on the stack of a passive vapor mitigation system is highly recommended although it does not reclassify the passive system as an active system. The wind turbine will only induce a vacuum to the subsurface when the wind is blowing and may impede the system flow if ice or snow accumulates on or in the turbine. However, solar powered wind turbines are available that enable longer operational periods to reduce sub-slab vapors.

6.2.3 Sub-Slab Ventilation Systems

Sub-slab ventilation systems (SSVS) employ the use of a venting layer below the slab that allows for the unimpeded movement of soil gas vapors laterally beyond the footprint of the building or to vent pipes placed in the venting layer to discharge to the atmosphere. In addition to the venting layer, perforated collection pipes may be installed laterally in the venting layer or on the perimeter of the venting material to assist the collection of the soil gas and route it to an exhaust point outside the building. With a SSVS design, VI is prevented by moving large quantities of air through the soil or from air supply ventilation pipes, into the venting layer, diluting the contaminants in the sub slab, and moving the contaminants laterally before they have a chance to enter the building (ITRC 2007). As an added protection, SSVS are generally used with a passive barrier to reduce the potential for VI.

These systems are used for new construction or when total slab replacement is required. The design and equipment for a SSVS is similar. They can be operated as a passive or active system. For a SSVS, the permeability of the sub-slab material is so high that it is not possible to maintain a sufficient pressure gradient in the sub-slab atmosphere to maintain a negative pressure.

This technique is also applicable to synthetic venting materials (e.g., geogrids) and aerated floor systems (Cupolex) that incorporate void spaces below the slab that allow unimpeded air flow.

6.2.4 Alternative Mitigation Methods

Mitigation methods that can be considered as an alternative or supplemental to a vapor mitigation technique when subsurface depressurization systems are not appropriate based on building construction or other technical justifications include:

- passive subsurface depressurization systems (existing buildings);
- active HVAC modifications (not appropriate for residential buildings);
- soil vapor extraction (SVE);
- aerated floor systems;
- spray on barriers (supplemental approach only);
- subsurface pressurization;
- heat recovery ventilator;

- IA treatment (designed as a temporary method);
- sealing vapor entrance points (supplemental approach only) ;
- limit or prohibit access to affected areas of building; and
- immediate removal of source.

The use of any alternative vapor mitigation methods shall be technically justified. Department approval is only necessary for situations where presumptive remedy (N.J.A.C. 7:26E-5.1(i)) is applicable. The alternative mitigation approach shall be equally protective as the recommended presumptive remedy (where applicable).

Additional information on the application, design and installation of vapor mitigation systems can be found in the following documents:

1. ASTM Standard Practice for Radon Control Options for the Design and Construction of New Low-Rise Residential Buildings, <http://www.astm.org/Standards/E1465.htm>
2. ASTM E2121-09 Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings, <http://www.astm.org/Standards/E2121.htm>
3. ASTM Standard Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical Affected Properties, <http://www.astm.org/Standards/E2435.htm>
4. ITRC Vapor Intrusion Pathway: A Practical Guideline, <http://www.itrcweb.org/Documents/VI-1.pdf>
5. USEPA Radon Prevention in the Design and Construction of Schools and Other Large Buildings.
6. USEPA Sub-Slab Depressurization for Low Permeability Fill Material, <http://www.epa.gov/radon/pubs/index.html>
7. USEPA Radon Reduction Techniques for Detached Houses, Technical Guidance, <http://www.epa.gov/radon/pubs/>
8. USEPA Model Standards and Techniques for Control of Radon in New Residential Buildings, http://www.epa.gov/radon/pdfs/model_standards.pdf
9. USEPA Building Radon Out: A Seep-by-Step Guide on How to Build Radon Resistant Homes, <http://www.epa.gov/radon/pubs/index.html>
10. USEPA Brownfields Technology Primer: Vapor Intrusion Considerations for Redevelopment, <http://www.epa.gov/brownfields/>; and
11. USEPA Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches, <http://www.clu-in.org/download/char/600r08115.pdf>
12. N.J.A.C 5:23-10 Radon Hazard Subcode http://www.state.nj.us/dca/divisions/codes/codreg/pdf_regs/njac_5_23_10.pdf

6.3 Mitigation System Design and Construction

6.3.1 System Design and Installer Qualifications

For the design and installation of a vapor mitigation system, utilize a New Jersey Certified Radon Mitigation Contractor; (<http://www.nj.gov/dep/rpp/radon/certmit2.htm>), an LSRP (http://www.nj.gov/dep/srp/srra/l srp/temporary_lsrp_list.htm), or licensed Professional Engineer who has specific experience in VI or radon building mitigation. A licensed electrician must

perform all electric work in accordance with local building codes. All designers and installers must have the required licenses and permits (Section 6.3.6) to complete the work. The vapor mitigation system should be certified (by the aforementioned person or firms) as being effective for addressing the VI pathway.

As with any mitigation work performed in existing structures, safety precautions are required for workers due to the potential exposure to hazardous materials that may be present in the building from construction or operations. All persons working on a VI case should be in compliance with all applicable OSHA regulations for working at hazardous waste sites (49 CFR 1910).

6.3.2 Pre-Mitigation Diagnostic Testing

Diagnostic testing for vapor mitigation systems consist of inspections, evaluations and physical measurements that are performed for the following reasons:

- Aid the designer and installer in the selection and application of the mitigation technology for the site-specific building conditions.
- Optimize the performance of the selected technology for vapor mitigation.
- Reduce the cost of installation of the selected technology for vapor mitigation.
- Provide an installation that will be safe for the building occupants.

The diagnostic tests can be performed in stages before the installation of the vapor mitigation system or in many cases they are completed simultaneous with the installation.

6.3.2.1 *Visual Inspection*

The visual inspection is to determine the suitability of the building for different vapor mitigation technologies. The inspection allows the installer to assess the difficulty of the installation based on the design and construction of the building (bi-level, additions, utilities, crawl spaces, etc.), where suction pipes can be located, routes for the suction and discharge piping, where the blower/fan can be installed and electrical requirements. At this time, assess the building for locations of possible VI through cracks, openings or utility entrance points with the use of a direct reading instrument or chemical smoke test. During the visual inspection materials should be identified that may need special handling and disposal (asbestos shingles, insulation, lead painted surfaces).

6.3.2.2 *Backdrafting*

When excessive depressurization of a building occurs (approximately -5 Pascal or greater) due to ventilation equipment and combustion devices, the potential exists for combustion exhaust gases (e.g., carbon monoxide) to be drawn into the building. This situation is backdrafting. Since many of the mitigation systems may affect the overall balance of airflow within a building, the investigator should determine if backdrafting is occurring prior to, and after the installation of a mitigation system. If an investigator has concerns about the backdrafting potential at a building prior to system installation, it should be recommended to the building owner that a licensed professional inspect the natural draft of the combustion or venting appliance for compliance with local codes and regulations and if needed, repair the system. Procedures for investigating

backdrafting are presented in several sources (USEPA 1993, ASTM 2007). A *Simple Smoke Visualization Test to Assess Backdrafting* can be found in Appendix I.

6.3.2.3 *Stack Effects*

Stack effect reduction techniques are an important aspect in minimizing the depressurization of a building to inhibit VI. The stack effect in a building is the upward movement of air inside a building from heated air rising and escaping the building through openings in the construction, thus causing an indoor pressure lower than in the soil around and below the building, promoting VI. Areas that should be evaluated for air leakage are included in Model Standards and Techniques for Control of Radon in New Residential Buildings (USEPA 1994a). All repairs and upgrades should be designed and installed to conform to applicable state and local building codes and maintain the function and operation of all existing equipment and building features.

6.3.2.4 *Communication Test*

For active subsurface depressurization systems, a communication test is a critical step in assessing the viability of the system to extend the sub-slab depressurization field beneath the entire slab and foundation (USEPA 1993). In some applications, such as large buildings, only a portion of a building may be required to have a mitigation system based on the source of the VOCs. A communication test should be conducted for each building as part of the design to assist in the determination of the number and locations of suction point(s) and fan size(s). Suction fields below the slab may be interrupted by existing sub-slab features (e.g., grade beams, footings, foundation walls) and require the installation of additional suction points. In other situations, sump pits can be utilized as suction points if properly sealed/ converted (ITRC 2007).

6.3.2.5 *Permanent Sub-slab Soil Gas Probes*

Upon successful completion of a communication test, permanent SSSG probes should be installed in locations that will indicate total slab or impact area depressurization. The probes should be located based on the findings of the communication test. This information will be useful during the commissioning of the system and during the OMM period. Observation holes installed during the communication test may be converted to permanent SSSG probes

The permanent sub-slab probes allow for repeatable measurements to confirm the negative pressure field during the OMM phase of the project (Section 6.5) and for SSSG testing for system terminations (Section 6.6). For the OMM phase of the project, the recommended number of permanent points to confirm sub-slab depressurization is four (4) probes for the first suction point plus two (2) probes for each additional suction point. The locations and number of probes can be altered depending on the site specific configuration of the extraction points, building's footprint, access and best professional judgment. An example design and procedure for installing a permanent sub-slab probe is included in Appendix J.

6.3.2.6 *Condensation*

During the design of the mitigation system, consideration should be given to the elimination of condensate that may collect in the piping of the mitigation system. The collection or freezing of

condensation can restrict the airflow through the piping decreasing the vacuum in the system, damaging system components and decreasing the operational lifetime of a blower or fan.

6.3.2.7 Alarms

Based upon the system design, installation location and preferences of the building occupants, a visible or audible device may be installed that will indicate if there is a loss in system power or vacuum. Typically, this consists of an electronic audible alarm or for larger systems a “call out” system connected by land-line phone. Clear instructions must be provided to the building owner with a name and phone number of the contact person in case an alarm is activated.

6.3.3 Sealing Vapor Entryways

For purposes of this technical guidance, vapor entryways include cracks in the subsurface walls or slab, openings in the slab, utility penetrations, floor drains and other related pathways for vapors to intrude into the building.

The sealing of vapor entryways discovered during the visual inspection should be assessed as part of the mitigation process. Sealing is usually not a stand-alone mitigation measure; however, it is an important component of any mitigation strategy and serves to enhance the effectiveness of all vapor mitigation approaches. In many cases, it is impracticable to access, locate and seal every potential infiltration point in an existing building, particularly slab-on-grade buildings or homes with finished basements. Therefore, diagnostic testing should be conducted prior to, during and after installation to ensure that a sufficient number of suction points have been installed to achieve acceptable vacuum levels over the affected areas of the slab to mitigate VI. A practical, rather than exhaustive level of sealing will generally result in a more conservative design, because the design is not relying on a completely sealed building shell in order to meet performance objectives, and seals may deteriorate over time.

To fill wall and slab cracks and prevent air leakage, sealants, such as synthetic rubbers, acrylics, oil-based sealants, swelling cement, and elastomeric polymers are appropriate (USEPA 2008a). Avoid sealants containing volatile compounds since they can introduce contaminants. Other locations that should be evaluated for sealing include:

- the tops of hollow block foundation walls
- utility conduits at the terminus with the building
- openings in the slab that allow for utility lines (water, sewer) to pass into a building for the toilet and bath. Remove access panels to check the slab for openings
- sumps provide a significant preferential pathway for vapors to migrate into a building. (install air tight covers over sumps to prevent VI but still allow active dewatering and sump pump access (USEPA 2008a))
- building access to a perimeter drain system around the basement floor connected to the sump
- water traps in floor drains may provide an entry route for vapors (repair the trap if leaking, periodically add water to the drain, or install a Dranjer type seal)

- buildings with highly cracked concrete slabs or a dirt floor (may have to repair the slab or install a new slab)

6.3.4 Gas Vapor Barriers

A gas vapor barrier should be included as part of a passive vapor mitigation system to eliminate the VI pathway in new construction. They are also used in the construction of SMD systems for the mitigation of crawl spaces and other low traffic areas over an earthen floor. A gas vapor barrier serves as a supplemental safety feature for both active and passive systems designed to increase the effectiveness of the overall design. As such, a gas vapor barrier is generally not acceptable as a stand-alone mitigation measure without the other components of an active or passive mitigation system.

Traditionally, the most commonly used material in building construction that is often referred to as a “vapor barrier” is 6 mil polyethylene. The American Concrete Standards Institute does not classify this material as a barrier but as a retarder to resist water vapor transmission. The term “vapor barrier” is often used interchangeably with “vapor retarder”. Vapor retarders are designed to retard the transmission of water vapor while vapor barriers are impermeable to water vapor. In reality, these types of sub-slab barriers are not designed or installed as a gas vapor barrier to eliminate VI; they are designed to minimize the inflow of water vapor through concrete from the subsurface. They are also not reliable for VI mitigation due to punctures, perforations, tears and incomplete seals during installation (ASTM 2007).

The type of material and physical characteristics of a gas vapor barrier should be evaluated to match the application in the VI mitigation system. Examples of some characteristics that may be evaluated for a gas vapor barrier include the following:

1. Thickness – Material thickness can be measured in mils (1 mil=0.001 inches), inches or mm. It is related to the tensile strength and puncture resistance properties. Liners are susceptible to punctures and tears during construction therefore they must be able to withstand normal construction activities. Recommended thicknesses for gas vapor barriers in construction is 40 mil HDPE (USEPA 2008A). A similar application of gas vapor barriers is for landfills which recommended a thickness of 30 mil or 60 mil HDPE (N.J.A.C. 7:26-2A.7). Other measures of thickness of gas vapor barriers have been used for VI mitigation projects. Generally, as the thickness of the gas vapor barrier material increases, the strength and durability of the material increases. The durability of the material should match the application and damage it may be exposed.
2. Resistance to water vapor transmission – Water vapor transmission properties are defined by the following terminology:
 - a. Water Vapor Transmission Rate – The water vapor transmission rate is the amount of water that can pass through a given area of material under specific conditions. Low water vapor transmission rates are required for gas vapor barriers.
 - b. Permeance – Permeance is a measure of the rate at which water vapor passes through a material under specific conditions and expressed as grain/[ft²*in. Hg*hr]. Permeance is a measure of material performance. The lower the permeance the more effective the vapor barrier is to resisting transmission of water vapor. Water vapor barriers are defined as material having permeance value of 1.0 or less.

- c. Permeability – Permeability is a measure of the time rate of water vapor transmission through a material under specific conditions. Permeability is a property of the material and is measured in perm-inches. Low permeability values are required for gas vapor barriers.
3. Solvent Vapor Transmission – The transmission rates of solvent vapors through a membrane may differ from water transmission rates due to the molecular size and attraction of the solvent vapor so the barrier material. The testing for solvent transmission rates are the same as those for water vapor only a solvent is used. This type of information may only be available from the manufacturer upon special request.
4. Chemical Resistance – Chemical resistance of the vapor barrier should be evaluated when used in areas where high levels of contaminants from contaminated soils or ground water are present. The vapor barrier must be chemically resistant to the chemicals present on-site to reduce the potential for chemical degradation of the vapor barrier.
5. Resistance to Puncture – Resistance to puncture is a measure of the force required to puncture a gas vapor barrier material. It can be used to evaluate the resistance of one type of force on different materials to aid in the selection evaluation of the material.
6. Tensile Strength – Tensile strength is a measure of the material resistance to tearing during the handling of the material for placement. The Tensile strength data can be used to compare different materials that are being evaluated for use in a specific application.

The above list contains a few of the different characteristics of gas vapor barrier material that should be evaluated to assist in the selection of the best material that will meet the goals of the application and the project.

In general, there are three types of gas vapor barriers used; they include sheet, spray on liquid and composite. Examples of construction materials for sheet gas vapor barriers include HDPE, linear low density polyethylene (LLDPE) and ethylene propylene diene monomer (EPDM). An example of liquid gas vapor barriers includes Liquid Boot[®]. Composite barriers are contain of 2 or more types of material construction (Geo-Seal[™]) or cross laminated materials.

During installation of a membrane for a vapor mitigation system, a QA/QC plan should be part of the installation. This plan should include inspections performed to ensure the proper material and/or thickness has been installed after the application. Inspect the membrane and seams to confirm they are sealed with the applicable sealant, proper amount of material overlap at the seams, proper seals around penetrations (e.g., water and sewer pipes, vent line), proper seal with the membrane and all edges of the foundation wall or footings, and that there are no holes or tears in the membrane (ITRC 2007). A smoke test should be performed to determine if any leaks developed during placement of the gas vapor barrier.

During the installation, consideration should be given to the design and installation of a monitoring system for sub slab vapors during the OMM of the project.

6.3.5 Construction and Electrical Permits

Construction and electrical codes are intended to protect the health, safety and welfare of building owners and occupants by establishing minimum construction standards. Vapor mitigation systems must be designed and installed in compliance with applicable mechanical,

electrical, building, plumbing, energy and fire prevention codes, standards and regulations of the local jurisdiction. It is important to check with the local municipal construction official to ascertain the appropriate permits or approvals, including inspections that are required for the installation of a vapor mitigation system.

6.3.6 Air Permits

The requirement for an Air Pollution Control (APC) Permit from the Department for a vapor mitigation system is based on the type of building, the location, the type and concentration of contaminant(s) from the discharge of the stack N.J.A.C 7:27 8.2(c). Refer to the *Decision Flow Chart for Air Pollution Control Permit* (Appendix K) and technical guidance (Appendix L) to determine whether an APC Permit is required for your system. For further details, contact the appropriate Department Air Enforcement Regional Office (<http://www.nj.gov/dep/enforcement/air.html>).

An ESRA may have as a precaution or require a treatment system for the stack discharge such as activated carbon, to remove volatile compounds. If these systems are used, they should be monitored for radiation due to the potential for the collection of radon gas by the carbon. Precautions must be used to protect workers and building occupants from this hazard.

6.3.7 Buildings with Existing Radon Systems

Occasionally, buildings will be identified for a VI investigation that may already have a radon mitigation system installed. The presence of a radon mitigation system may not preclude the need to assess the VI pathway and possibly upgrade the system to address volatile contaminants. This can be determined by IA sampling and analysis.

If an existing radon mitigation system requires upgrades to meet the IASL for VI, regulations require that only a New Jersey certified radon mitigation professional can complete the alterations to a radon system (N.J.S.A. 26:2D-70 et seq.). Any person not certified and performing radon services shall be subject to the criminal penalties in N.J.S.A. 26:2D-77.

6.4 Post-Mitigation Activities

6.4.1 Institutional and Engineering Controls

ESRA that involve the installation of subsurface depressurization system, similar VI mitigation devices or engineering controls (including but not limited to those actions discussed in Section 6.2) do not require an institutional control.

The investigator should consult the Technical Rules (N.J.A.C. 7:26E-6 and 8) and the Administrative Requirements for Remediation of Contaminated Sites or ARRCs (N.J.A.C. 7:26C-7) for institutional and engineering control requirements. Ground water CEAs and deed notices are the two institutional controls with ongoing monitoring and evaluation requirements potentially applicable to the VI pathway. The investigator should coordinate the MME requirements for institutional controls with the post-mitigation sampling and OMM provisions

for the ESRA discussed in Sections 6.4.2, 6.4.3 and 6.5 below. A remedial action permit, issued pursuant to N.J.A.C. 7:26C-7, would incorporate both types of monitoring requirements.

When implementing a ground water remedial action, the investigator shall comply with the applicable VI related ground water CEA requirements (regulations cited above), which address potential future VI risk that was not mitigated by an ESRA. Deed notices require addressing VI risks from soil contamination or volatile contaminant(s) in a landfill. The option to use a deed notice to address VI risks in other circumstances is available if the affected property owner is willing to establish one (<http://www.state.nj.us/dep/srp/regs/deednotice/>). However, use of a deed notice would not substitute for compliance with the CEA requirements applicable to VI risk from ground water contaminants.

N.J.A.C. 7:26E-6.2 requires that a remedial action work plan include a plan for MME of institutional controls pursuant to the requirements of N.J.A.C. 7:26E-6.3 and 8.6 (CEA) or 8.5 (deed notices) or N.J.A.C. 7:26C-7, as applicable. Technical guidance is provided below regarding MME plans and biennial certification requirements with regard to the VI concerns and the implementation of these institutional controls at the affected building. Instructions for the applicable Remedial Action Protectiveness/Biennial Certification Form also provide relevant information (<http://www.nj.gov/dep/srp/srra/forms/>).

The MME plan should include provisions to monitor for future changes in use of the property where the change in use could increase the VI risk. For example, where nonresidential screening levels (SGSL, IASL, or OSHA values) are used as part of the mitigation, it would be appropriate for the MME plan to include obtaining agreements with affected property owners that allow periodic assessment of property use changes which could affect the protectiveness of the remedy (e.g., conversions to residential use).

Likewise, the option to use site-specific building parameters (e.g., ventilation rate changes, building size modifications, positive pressure controls) to address VI risks would necessitate a property owner agreement to allow ongoing monitoring at the affected building/property to ensure the remedy is still protective. Such agreements would ensure the applicable building parameters continue to mitigate VI risk if any changes to property use should occur such as building renovation or major alterations to HVAC system construction or operation.

Other changes in the property use overlying the footprint of a CEA that may alter the risk of VI include new construction, changes in ground surface cover, storm water management, and filling and/or excavation operations. The investigator should periodically monitor the site for planned or existing changes in property use and ownership and changes in building use/conditions as appropriate based on site-specific conditions. The monitoring frequency should ensure that any additional remediation needed due to property use changes, can be completed quickly enough to allow submittal of the biennial certification (that the remedy remains protective) in the required timeframe.

For example, if a dry cleaning business overlying a PCE plume closes and the building now houses a restaurant, ground water, sub-slab and/or IA sampling may be needed to evaluate the potential VI risk. Such sampling can take a significant amount of time to complete and any required mitigation will necessitate even more time. In many cases, all investigation and

mitigation would need to be completed to certify that the institutional control and remedy remain protective. Therefore, frequent monitoring for these kinds of land and building use changes is appropriate at sites where such changes are possible.

Statutory authority for requiring submittal of the certification and the supporting documentation that the remedy remains protective is in the Brownfield and Contaminated Site Remediation Act at N.J.S.A. 58:10B-13.1 and 13.2.

6.4.2 System Commissioning (Post-Mitigation Diagnostic Test)

Once the vapor mitigation system is installed, it should be commissioned to verify that it is functioning consistent with the mandated performance specifications and to establish an operational baseline. Due to subsurface conditions (e.g., high moisture content), sufficient time will be necessary for the sub-slab area to reach equilibrium after the installation of the vapor mitigation system. Thus, the baseline performance measurements should be collected no sooner than 30 days after the system is activated (Commission Timeframe). The 30 day timeframe also allows the building time to vent prior to collecting verification IA samples.

The system commissioning should include:

- visual inspection of the system with the aid of the *Vapor Intrusion Mitigation System Inspection Checklist* (Appendix M);
- establishment of an operational baseline from appropriate commissioning parameters;
- determination as to whether alterations or augmentation of the system are required; and,
- trouble-shoot any problems (noise, vibration, condensate generation, complaints, etc.).

Some vapor mitigation systems may require a shorter or longer commissioning timeframe based on site-specific factors.

6.4.2.1 Vapor Intrusion Mitigation System Inspection Checklist

To assist in the evaluation of the mitigation installation, a check list has been developed to aid in the design, construction and evaluation of a vapor mitigation system. The *Vapor Intrusion Mitigation System Inspection Checklist* (Appendix M) identifies a series of minimum technical design provisions that should be incorporated for VI mitigation systems. All applicable items contained in the checklist should be incorporated into the design for any VI mitigation system unless technical justifications are provided. Modifications from what is detailed in the checklist may be appropriate during the installation of the mitigation system due to site-specific building factors and/or preferences of the occupant/owner.

6.4.2.2 Active System Diagnostic Measurements

Diagnostic testing during the system commissioning is used to determine the operational parameters of the mitigation system, performance of the system and establish a baseline for the operational parameters. Measurements can be obtained from individual extraction points, piping headers or at the fan/blower. Types of system diagnostic measurements obtained during the commissioning period of the mitigation system will vary based on the design and construction of

the mitigation system. System diagnostic measurements can be obtained with direct reading instruments. Measurements can include but are not limited to the following:

- Vacuum;
- temperature;
- DRI-VOC, methane and non-methane concentrations;
- % oxygen;
- air flow; and,
- any system specific measurements that will aid in determining the system performance.

These diagnostic measurements or system commissioning values can be used during the OMM phase of the project to confirm steady state operational conditions and provide multiple lines of evidence that the mitigation system continues to prevent VI in lieu of IA testing.

6.4.2.3 Passive System Diagnostic Measurements

Diagnostic testing of a passive vapor mitigation system can be difficult due to the low and variable flow rates and vacuum pressures generated with this type of mitigation system. Flow measurements can be obtained from the vent pipe but may be below the limits for a pitot tube, a hotwire anemometer or other device. Therefore, the only diagnostic testing available for a passive system is the use of IA (and possibly SSSG) sampling and analysis.

6.4.2.4 Subsurface Vacuum Measurements

Subsurface vacuum measurements are used to confirm the pressure differential across the slab in the target area (entire or partial slab). Vacuum measurements from permanent sub-slab probes may be in the range of 0.01 to 0.001 inches of water (2.5-0.25 Pascal). Therefore, a digital manometer with an accuracy and resolution to properly measure the vacuum is required. Smoke testing can be used to determine if there is a vacuum in the sub-slab but it is only a qualitative test. At low vacuums, the use of a chemical smoke test at the sub-slab probes may be difficult to determine the presence of vacuum in the sub-slab.

For active subsurface depressurization systems, sub-slab vacuum measurements can be obtained from the permanent probes installed during the communications test (Section 6.3.2.5). In general, an active SSDS should achieve a pressure differential of at least 0.004 inches of water (1 Pascal) across the slab for the mitigation of VI.

For active subsurface ventilation systems where subsurface materials are highly permeable, large volumes of air are drawn through the subsurface soils with little pressure drop. In these situations, sub-slab depressurization measurements across the slab may be difficult where soil conditions limit reasonably achievable depressurization levels. If measurable vacuum measurements are not obtainable, utilize flow measurements at the fan inlet.

As previously described, the only definitive diagnostic testing that may be available for a passive system is the use of IA and SSSG sampling and analysis.

6.4.2.5 Backdraft Testing

After system installation, a backdraft test (Appendix I) should be performed on combustion appliances to confirm that backdrafting is not occurring due to the operation of an active mitigation system (6.3.2.2). If the test shows the potential for backdrafting, immediately turn off the mitigation system, determine the cause, and remediate prior to the operation of the system.

6.4.2.6 Building Owner Notification of System Operations

The investigator should identify and describe the various components of the vapor mitigation system to the owner/occupant, including the purpose of the pressure gauge and the contact information if they suspect a problem. This information should also be included in the IEC ESRA Report or the VC Mitigation Response Action Report specific to the system.

6.4.2.7 Conversion Factors

For reporting purposes, diagnostic test results may be reported in various units. Included in Table 6.1 is a list of unit conversions for some of the common measurements obtained during a VI investigation and diagnostic testing. The Department does not stipulate the reporting units for diagnostic testing with the exception of soil gas and air concentrations ($\mu\text{g}/\text{m}^3$).

Table 6.1
Unit Conversions for VI Mitigation (ESE 1982)

Unit	Multiplied by	To Obtain
Inches of water	249.1	Pascal
Inches of water	7.355×10^{-2}	Inches of mercury
Inches of water	2.4581×10^{-3}	Atmospheres
Inches of mercury	3.342×10^{-2}	Atmospheres
Inches of mercury	2.54×10^1	Millimeters of mercury
Atmospheres	101,325	Pascal
Atmospheres	2.992×10^1	Inches of mercury
Atmospheres	7.6×10^2	Millimeters of mercury
Pounds per square inch	6894	Pascal
Pounds per square inch	6.804×10^{-2}	Atmospheres
Pounds per square inch	2.036	Inches of mercury
Bar	100,000	Pascal
Bar	9.869×10^{-1}	Atmospheres
Liter	3.531×10^{-2}	Cubic feet
Liter	1,000	Cubic meter
$^{\circ}\text{F}$	$5/9 (^{\circ}\text{F}-32)$	$^{\circ}\text{C}$
$^{\circ}\text{C}$	$9/5 ^{\circ}\text{C}+32$	$^{\circ}\text{F}$
$\mu\text{g}/\text{m}^3$	24.45/MW	ppbv
ppbv	MW/24.45	$\mu\text{g}/\text{m}^3$
Pascal	0.004	Inches of water

6.4.3 Verification Sampling

Verification sampling (VS) is recommended to confirm the system performance in effectively reducing contaminant levels in the IA. Irrespective of the vapor mitigation technique selected, IA sampling is necessary as part of the MLE to confirm the mitigation technique was effective in reducing the contaminant levels below the Department's IASL. For passive and alternative systems, sub-slab samples should also be obtained to aid in determining the effectiveness of the mitigation. Implement the VS immediately following (same day) as the commissioning of the system – usually 30 days or more after the system start-up. VS designs are included in Table 6-2.

VS analysis is only required for the COCs and their breakdown products. The IA sample(s) should be collected in the basement (or lowest floor) and biased towards worst case locations identified during previous sampling events and/or professional judgment.

6.4.4 Engineered System Response Action Report

The ESRA report documents the conditions before and after the installation of the vapor mitigation system. The timeframe for the submission of an ESRA report is referenced in Section 6.1.2.4 for VCs and IECs and Appendix B. Prepare a separate report for each property with a copy presented to the property owner. The ESRA report shall contain the following (N.J.A.C. 7:26E-6.7):

- general history and physical setting of the site;
- identification of receptors in the building;
- map of building location;
- design and as-built drawings showing all system components and electrical connections, as well as IA and SSSG sampling locations, extraction and observation holes, and mechanical combustion devices (hot water heater, clothes dryer, etc.);
- description and dates of each action taken including all sampling events, IRA and mitigation taken (e.g., IA sampling, communication testing, commissioning testing, etc.);
- summary and justification for field modifications to the system;
- all pre-mitigation communication testing results;
- pre-and post-mitigation IA and SSSG sampling results with interpretation;
- building survey forms for each sampling event;
- any building permits required by the local municipality;
- copy of the completed *Vapor Intrusion Mitigation System Inspection Checklist*;
- photos of system installation;



Figure 6-1. Inspection of SSD fan and weatherproof cover

- summary of mitigation system diagnostic test measurements and commissioning values;
- air permit evaluation data (if required);
- certification of the report from a professional engineer, LSRP or Certified Radon Mitigation Specialist;
- OMM Plan; and,
- Monitoring, Maintenance and Evaluation Plan (if applicable).

For all documents prepared for the VI pathway, including letters sent to building occupants, the results are to be reported in units of $\mu\text{g}/\text{m}^3$. The analytical units of parts per billion by volume are no longer acceptable.

Additional information that is required in the ESRA Report submission can be found in the Department's Immediate Environmental Concern Technical Guidance, 2011 (<http://www.nj.gov/dep/srp/guidance/>).

6.5 Operation, Maintenance and Monitoring

To verify the continued proper operation of the mitigation system, an OMM program shall be implemented pursuant to N.J.A.C. 7:26E-1.14(d). The program should consist of inspections, diagnostic measurements from the mitigation system, and IA sampling (if applicable) to verify the proper operation indicating the continued system effectiveness in the mitigation of VI. OMM inspection frequencies and sampling designs are included in Table 6-2. A Vapor Intrusion Mitigation System Inspection Checklist (Appendix M) along with a Subsurface Depressurization Monitoring Form (Appendices N or O) or similar documentation should be completed to assist and document each OMM visit.

The design of some mitigation systems may not allow for diagnostic measurements of the system to determine if it is operating properly. In these cases, sampling of IA (or SSSG) may be the only diagnostic measurement available to confirm the mitigation of the VI pathway.

IA sample analysis for the OMM program is only required for the COCs and their breakdown products. The sampling locations may also be reduced based on previous analytical data and technical justification.

To document and report the observations made during the vapor mitigation system inspections, a monitoring report should be generated consistent with N.J.A.C. 7:26E-8.7(b) and certified consistent with N.J.A.C. 7:26E-8.7(c).

Part of the OMM program for an active mitigation system may require the payment for electrical service. If conditions permit, the use of renewable energy technology should be utilized to supplement the line service and eliminate or reduce energy costs. A separate power drop can be installed to allow the person responsible for conducting the mitigation to pay for energy costs directly or the building owner can be reimbursed periodically for electrical costs incurred due to the power usage of the mitigation system. If the investigator will be reimbursing the homeowner for the electrical cost of the mitigation system, a simple calculation can be used to determine the

reimbursement cost to the homeowner based on energy supply cost. These calculations are included in Appendix P.

6.5.1 Variations in Baseline Parameters

During the OMM phase of a project, variations from established system commissioning (baseline) values or data trends may occur. A variation is defined as the % difference in the measured value from the system commissioning value as calculated below:

$$\% \text{ Difference} = [|V_1 - V_2| / ((V_1 + V_2) / 2)] * 100\%$$

A variation can also be determined by statistical calculations to determine if a value is significantly different from the system commissioning value or data trend. Variations from commissioning (baseline) values that are greater than 20% should trigger a reevaluation of the vapor mitigation system. The 20% variation provision should never be applied to analytical results of IA and soil gas samples. The analytical results should be compared directly to the applicable screening levels.

These occurrences of variations may be due to system malfunctions, improper design, changes in the sub-slab environment or changes to the building structure. If the cause of the deviation cannot be determined or repaired, the system should be re-commissioned.

If variations in measurements from SSDS commissioning values are greater than 20% but, the sub-slab probe vacuum measurements obtained across the building slab or mitigation area are greater than 0.004"wc, the system can be considered protective from VI and IA testing should not be required. The new sub-slab vacuums and system diagnostic measurements will then become the new system commissioning values.

In cases where sub-slab data are not available or exceedances of the IASL were measured, a corrective action should be completed that would involve an evaluation of the system for repairs, augmentation or redesign and implementation. After the work has been completed, VS should be repeated and re-commissioning of the system completed.

For passive or alternative system designs, if a second corrective action is required the system should be upgraded or converted to an active depressurization or venting system.

Included in Table 6.2 is a summary of the OMM mitigation and monitoring parameters, timeframes and corrective actions for various ESRAs.

Table 6.2
Vapor Mitigation Verification and OMM Criteria

	Active SSDS or SSVS	Passive SSDS or SSVS	Alternative VI Mitigation Systems
Recommend Use	Existing buildings and IRA	New building construction only	When technically justified based on site-specific features (Section 6.2.4)
Commission Timeframe	30 - 45 days after system startup		
System Commission Parameters	IA samples, sub-slab negative pressure field measurements, system air flow measurements, pressure measurements	1) IA samples 2) SSSG (or void space) samples 3) Air flow measurements for SSVS	1) IA samples 2) SSSG or void space samples, sub-slab negative pressure field measurements and/or other system-specific parameters selected
VS	Perform immediately following system commissioning. Minimum one round of IA samples in heating season. ¹ Collect appropriate system diagnostic measurements to establish baseline values.	Perform immediately following system commissioning. Minimum one round of IA samples in heating season. ¹ In addition, collect appropriate number of sub-slab (or void space) soil gas samples to establish baseline values.	Perform following system commissioning. Minimum one round of IA samples in heating season. ¹ In addition, collect appropriate number of sub-slab (or void space) soil gas samples and/or system diagnostic measurements to establish baseline values.
OMM	<p>First year OMM:</p> <ol style="list-style-type: none"> Quarterly inspection of system³. Verify the commissioning values³ <p>Second year OMM & beyond:</p> <ol style="list-style-type: none"> Annual inspection of system³ Annual collection of appropriate system diagnostic measurements and verify consistency³ with baseline values 	<p>First year OMM:</p> <ol style="list-style-type: none"> Quarterly system³ inspection. Sampling of IA and SSSG (or void space) during heating season¹ following VS sampling <p>Second year OMM:</p> <ol style="list-style-type: none"> Semi-annual inspection of system³ SSSG (or void space) sampling during heating season¹ <p>Third year and beyond:</p> <ol style="list-style-type: none"> Annual inspection of system³ IA and SSSG (or void space) sampling during heating season¹ every year until the results are consistent; THEN IA sampling during the heating season every 5 years. 	<p>First and second year OMM:</p> <ol style="list-style-type: none"> Quarterly inspection of system³. Annual sampling of IA during heating season¹. Annual SSSG (or void space) sampling (when appropriate). Quarterly collection of commissioning measurements and verify consistency². <p>Third year OMM & beyond:</p> <ol style="list-style-type: none"> Annual inspection of system³. Annual collection of appropriate commissioning parameters and verify consistency^{2,3}. SSSG (or void space) sampling (when appropriate) and IA sampling during heating season¹ every three years²
Corrective actions during VS or OMM	For an exceedance of NJDEP IASL ⁴ or variation ⁵ from commissioning values: 1) Check system for malfunctions, modify or augment the system. 2) Re-commission the system. 3) Collect VS & re-start OMM	For an exceedance of NJDEP IASL ⁴ or variation ⁵ from commissioning values: 1) Check system for malfunctions, modify or augment the system. 2) Re-commission the system. 3) Collect VS & re-start OMM	For an exceedance of NJDEP IASL ⁴ or variation ⁵ from the commissioning values: 1) Check system for malfunctions, modify or augment the system. 2) Re-commission the system. 3) Collect VS & re-start OMM
		<p>Convert to active system if:</p> <ol style="list-style-type: none"> Second corrective action is required; or Increasing trends in SSSG (or void space) samples that exceed NJDEP SGSLs during OMM (not VS) 	<p>Upgrade to active SSDS if:</p> <ol style="list-style-type: none"> Second corrective action required; or Increasing trends in SSSG (or void space) soil gas results that exceed NJDEP SGSLs during OMM (not VS)

- 1 – Heating season is from November 1 to March 31.
- 2 –If appropriate for the evaluation of the ESRA
- 3 – For systems that are larger and a greater complexity may require a greater frequency of inspections.
- 4 – Exceedances are concentrations of contaminants not attributable to background
- 5 – A variation of greater than 20% difference from the system commissioning value or statistical evaluation of the data indicating a significant difference.

6.5.2 Long-Term Monitoring

There are situations where LTM, without system installation, may be the appropriate mitigation action. Specifically, LTM can be performed when the investigation of a building reveals that the soil gas results are in excess of the applicable Department SGSL and the IA results are below the Department IASL. The frequency of inspections and IA sampling for buildings with soil gas concentrations <10X the Department SGSL and ≥10X the Department SGSL are summarized in Table 6.3. The building inspection should include an evaluation of the competence of the building envelope to determine if any changes have been made or formed to allow vapors to easily enter the building (e.g., installation of a sump, addition to the building, cracks in floor, etc.). The collection of SSSG samples is optional during LTM.

Monitoring can be altered based on professional judgment. Examples include decreasing the IA sampling frequency when long-term trends are available or ground water concentrations are decreasing. If soil gas or ground water concentrations increase, an increase in sampling frequency should be implemented. If IA sampling yields results for the COCs that are above the Department IASL at any time (with consideration of background sources) an ESRA should be implemented. LTM should be incorporated into the MME for the CEA/deed notice. Monitoring can be terminated following the guidelines set in *System Termination* (Section 6.6).

Table 6.3
Long Term Monitoring Sampling Designs

Sub-Slab Soil Gas >10X NJDEP SGSL	Sub-Slab Soil Gas >NJDEP SGSL and ≤10X NJDEP SGSL
<p><u>First and second year LTM:</u></p> <ol style="list-style-type: none"> 1 Semi-annual inspection of building. 2. Semi-annual sampling of IA². <p><u>Third year LTM & beyond:</u></p> <ol style="list-style-type: none"> 1. Annual inspection of building. 2. Annual sampling of IA in heating season¹. 	<p><u>First and second year LTM:</u></p> <ol style="list-style-type: none"> 1 Semi-annual inspection of building. 2. Annual sampling of IA during heating season¹. <p><u>Third to sixth year LTM:</u></p> <ol style="list-style-type: none"> 1. Annual inspections of building. 2. Sampling of IA in years 4 & 6 of LTM¹. <p><u>After sixth year LTM:</u></p> <ol style="list-style-type: none"> 1. Annual inspection of building. 2. Sampling of IA every 5 years in heating season¹.

- 1 – Heating season is from November 1 to March 31 (Winter).
- 2 – Winter and summer.

6.6 System Termination

Site cleanup efforts should reduce contaminant levels in ground water, soil, soil gas, etc. to levels that will no longer result in VI. Once it is concluded that the VI source has been properly remediated in accordance with N.J.A.C. 7:26E, sampling should be implemented to allow for possible cessation of operations of the VI mitigation system and possible removal of institutional controls can be implemented.

System termination sampling is based on the results of IA and SSSG sample results. Samples should be obtained at the same locations that were used to identify the VI impacts. Analytical parameters for the system termination samples should include the same list of COCs analyzed during the verification sampling.

Prior to sampling for system termination, shut down the mitigation system for a period of 30-45 days to allow re-development of subsurface contaminant concentrations, if present.

A vapor mitigation system or LTM may only be terminated with Department approval based on contaminant levels below the appropriate screening levels for IA and soil gas for two (2) rounds of sample data with at least one (1) round performed during the heating season. The mitigation system should be turned back on between sampling events to maintain the protectiveness from potential impacts to people in the building.

Upon system termination, arrangements should be made with the building owners to remove any equipment and/or monitoring devices associated with the mitigation system or LTM operations and perform repairs to the building from their removal.

REFERENCES

- Abreu, L.D.V., R. Ettinger and T. McAlary. 2009. "Simulated soil vapor intrusion attenuation factors including biodegradation for petroleum hydrocarbons," *Ground Water Monitoring and Remediation*, **29**(1):105-117.
- ASTM. 2007. Standard Guide for Assessing Depressurization-Induced Backdrafting and Spillage from Vented Combustion Appliances. ASTM E 1998 – 02 (2007). ASTM, West Conshohocken, PA.
- ASTM. 2008. Standard Practice for Radon Control Options for the Design and Construction of New Low-rise Residential Buildings. ASTM E 1465-08a. ASTM, West Conshohocken, PA.
- ASTM. 2009. Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings. ASTM E 2121-09. ASTM, West Conshohocken, PA.
- ASTM. 2010a Standard Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical-Affected Properties. ASTM E 2435-05(2010)e1. ASTM, West Conshohocken, PA.
- ASTM. 2010b Standard Guidance for Vapor Encroachment Screening on Property Involved in Real Estate Transactions. E2600-10. ASTM, West Conshohocken, PA.
- Code of Federal Regulations. 1991. 40 CFR 60. Appendix A to Part 60 – Test Methods.
- Dawson, H.E. and T. McAlary (2009). A compilation of statistics for VOCs from post-1990 indoor air concentration studies in North American residences unaffected by subsurface vapor intrusion. *Ground Water Monitoring and Remediation*, **29**(1); 60-69.
- DeVaull, G.E., R.A. Ettinger, J.P. Salanitro, and J.B. Gustafson. 1997. "Benzene, Toluene, Ethylbenzene and Xylenes [BTEX] Degradation in Vadose Zone Soils during Vapor Transport: First-Order Rate Constants." In *Proceedings of the Petroleum Hydrocarbons and Organic Chemicals in Groundwater Conference: Prevention, Detection and Remediation*, November 12-14, 1997, Houston, TX. Ground Water Publishing Company, Westerville, Ohio, 365-379.
- Environmental Science & Engineering, Inc. (ESE). 1982. ESE Handbook.
- Folkes, D.J. and J.P. Kurtz 2002a. Background Concentrations of Selected Chlorinated Hydrocarbons in Residential Indoor Air. In: *Indoor Air 2002: Proceedings of the 9th International Conference on Indoor Air Quality and Climate*, ed. Levin, H., G. Bendy and J. Cordell, Santa Cruz, CA, pp. 920-925.

- Folkes D. J. and Kurz, D.W. 2002b. Efficacy of Sub-Slab Depressurization for Mitigation of Vapor Intrusion of Chlorinated Organic Compounds. In proceedings of Indoor Air, Monterey, CA.
- Golder Associates. 2008. Report on Evaluation of Vadose Zone Biodegradation of Petroleum Hydrocarbons: Implications for Vapour Intrusion Guidance. Golder Associates, Burnaby, British Columbia, Canada, 06-1412-130, submitted to Health Canada, Winnipeg, Manitoba, Canada.
- Hartman, B. 2010. "The Vapor-Intrusion Pathway: Petroleum Hydrocarbon Issues," *LUSTLine* Bulletin 66, December 2010.
- Hodgson, A.T. and H. Levin 2003. Volatile organic compounds in indoor air: a review of concentrations measured in North America since 1990. Lawrence Berkley National Laboratories Report LBNL-51715. <http://eetd.lbl.gov/ie/pdf/LBNL-51715.pdf> (accessed July 29, 2009).
- Interstate Technology & Regulatory Council (ITRC). 2007. Vapor Intrusion Pathway: A Practical Guideline. ITRC Vapor Intrusion Team. www.itrcweb.org.
- Johnson, P.C. and R.A. Ettinger. 1991. "Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings," *Environmental Science and Technology* **25**: 1445-1452.
- Lahvis, M.A., A.L. Baehr, and R.J. Baker. 1999. "Quantification of aerobic biodegradation and volatilization rates of gasoline hydrocarbons near the water table under natural attenuation conditions," *Water Resources Research*, **35**:753-765.
- McAlary, T. 2009. Helium Leak Test. Geosyntec Consultants, Guelph, Ontario, Canada.
- McAlary, T.A. P. Nicholson, H. Groenevelt, D. Bertrand, 2009. "A Case Study of Soil-Gas Sampling in Silt and Clay-Rich (Low Permeability) Soils", *Ground Water Monitoring & Remediation*, 29: 144-152.
- New Jersey Administrative Code. 2007. N.J.A.C. 5:23-10 - Radon Hazard Subcode. Title 5, Chapter 23, Subchapter 10.
- New Jersey Department of Environmental Protection (NJDEP). 2005a. Field Sampling Procedures Manual (FSPM).
- New Jersey Department of Environmental Protection (NJDEP). 2005b. Vapor Intrusion Guidance (VIG). <http://www.nj.gov/dep/srp/guidance/vaporintrusion/>.
- New Jersey Department of Environmental Protection (NJDEP). 2008. Remediation Standards. New Jersey Administrative Code N.J.A.C. 7:26 D. <http://www.state.nj.us/dep/srp/guidance/rs/>.

- New Jersey Department of Environmental Protection (NJDEP). 2011. Technical Requirements for Site Remediation. New Jersey Administrative Code N.J.A.C. 7:26 E.
- New York State Department of Health (NYSDOH). 2006. Guidance for Evaluating Soil Vapor Intrusion in the State of New York. Center for Environmental Health, Albany, NY.
- O'Brien & Gere. 2009. Sub-Slab Vapor Sample Collection Procedures in Buildings with Existing Sub-Slab Depressurization Systems.
- Rago R., McCafferty R. and Rezendes 2005. Haley and Aldrich. Summary of Residential Indoor Air Quality Data, Massachusetts Indoor Air Background Study.
- Reynolds, P.A. 2007. The Use of Tracer Gas in Soil Vapor Intrusion Studies. In Proceedings of the Annual International Conference on Soils, Sediments, Water and Energy, Volume 12, Article 39. The Berkeley Electronic Press.
- Rivett, M.O. 1995. "Soil-Gas Signatures from Volatile Chlorinated Solvents: Borden Field Experiments," *GROUND WATER*, **33**(1).
- Roggemans, S., C.L. Bruce, P.C. Johnson, and R. L. Johnson. 2001. Vadose Zone Natural Attenuation of Hydrocarbon Vapors: An Empirical Assessment of Soil Gas Profile Data. API Technical Bulletin No. 15.
- Sanders, P.F. and I. Hers. 2006. "Vapor Intrusion in Homes Over Gasoline-Contaminated Groundwater in Stafford, NJ," *Ground Water Monitoring and Remediation*, 26 (1).
- Sexton, K., J.L. Adgate, G. Ramachandran, G.C. Pratt, S.J. Mongin, T.H. Stock, and M.T. Morandi. (2004). "Comparison of Personal, Indoor, and Outdoor Exposures to Hazardous Air Pollutants in Three Urban Communities," *Environ. Sci. Technol.*, **38** (2): 423-430.
- Squillace, P.J., J.F. Pankow, N.E. Korte and J.S. Zogorski. 1997. "Review of the environmental behavior and fate of methyl tert-butyl ether," *Environmental Toxicology and Chemistry*, **16**(9): 1836-1844.
- U.S. Department of Agriculture (USDA). Soil Texture Calculator
<http://soils.usda.gov/technical/aids/investigations/texture/>
- U.S. Environmental Protection Agency (USEPA). 1987. The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis, Volume 1, U.S. Environmental Protection Agency, Washington, DC, EPA-600/6-87 002a (PB88-100060).
- U.S. Environmental Protection Agency (USEPA). 1991. Handbook – Sub-Slab Depressurization for Low Permeability Fill Material – Design and Installation of a Home Radon Reduction System. EPA/625/6-91/029, July 1991.

- U.S. Environmental Protection Agency (USEPA). 1993. Radon Reduction Techniques for Existing Detached Houses – Technical Guidance (Third Edition) for Active Soil Depressurization Systems. EPA 625/R-93-001, October 1993.
- U.S. Environmental Protection Agency (USEPA). 1994a. Model Standards and Techniques for Control of Radon in New Residential Buildings. Air and Radiation (6604-J); EPA 402-R-94, March 1994.
- U.S. Environmental Protection Agency (USEPA). 1994b. Radon Prevention in the Design and Construction of Schools and Other Large Buildings. Office of Research and Development. EPA/625/R-92/016, June 1994.
- U.S. Environmental Protection Agency (USEPA). 1999. Compendium of Methods for Toxic Air Pollutants, Second Edition, Method TO-15. Center for Environmental Research Information, Office of Research and Development. Cincinnati, OH.
- U.S. Environmental Protection Agency (USEPA). 2001a. Healthy Buildings, Healthy People: A Vision for the 21st Century. Office of Air and Radiation.
- U.S. Environmental Protection Agency (USEPA). 2001b. Building Radon Out: A Step-by-Step Guide on how to build Radon-Resistant Homes. Office of Air and Radiation. EPA/402-K-01-002.
- U.S. Environmental Protection Agency (USEPA). 2002a. "Role of Background in the CERCLA Cleanup Program." Office of Solid Waste and Emergency Response.
- U.S. Environmental Protection Agency (USEPA). 2002b. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance). Office of Solid Waste and Emergency Response.
- U.S. Environmental Protection Agency (USEPA). 2005. Guidance for Evaluating Landfill Gas Emissions for Closed or Abandoned Facilities. Office of Research & Development. EPA-600/R-05-123a
- U.S. Environmental Protection Agency (USEPA). 2006. Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples, National Risk Management Research Laboratory. EPA/600/R-05/147.
- U.S. Environmental Protection Agency (USEPA). 2008a. Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches. National Risk Management Research Laboratory. EPA/600/R-08-115.
- U.S. Environmental Protection Agency (USEPA). 2008b. Brownfield Technology Primer: Vapor Intrusion Considerations for Redevelopment. Solid Waste and Emergency response. EPA 524-R-08-001. March 2008.

- Wallace, L.A. 1986. Personal exposure, indoor and outdoor air concentrations, and exhaled breath concentrations of selected volatile organic compounds measured for 600 residents of New Jersey, North Dakota, North Carolina and California. *Toxicol. Environ. Chem.* 12,215-236.
- Weisel, C.P., J. Zhang, B.J. Turpin, M.T. Morandi, S. Colome, T.H. Stock and D.M. Spektor. 2005. Relationships of indoor, outdoor, and personal air (RIOPA): Part I. Data Collection and Descriptive Analyses. HEI Research Report 130; NUATRC Research Report 7. Health Effects Institute, Boston, MA, and Mickey Leland National Urban Air Toxics Research Center, Houston, TX.
- Weisel, C.P. 2006. Investigation of Indoor Sources of VOC Contamination. Final report to the Division of Science, Research and Technology, New Jersey Department of Environmental Protection, Trenton, NJ.
- Weisel, C.P., S. Alimokhtari and P.F. Sanders. 2008. Indoor air VOC concentrations in suburban and rural New Jersey. *Environ. Sci. Technol.* 42(22), 8231-8238.
- Wisconsin Department of Natural Resources (WDNR). 2000. Guidance for Documenting the Investigation of Utility Corridors. PUBL-RR-649.
- Won, D., Corsi, R.L., and Rynes, M. 2000. "New Carpet as an Adsorptive Reservoir for Volatile Organic Compounds," *Environmental Science & Technology* 34 (19): 4193-4198.
- Zhu, J., R. Newhook, L. Marro, and C.C. Chan. (2005). "Selected Volatile Organic Compounds in Residential Air in the City of Ottawa, Canada," *Environ. Sci. Technol.*, 39 (11):3964-3971.