June 2008

RRD OPERATIONAL MEMORANDUM No. 4

SITE CHARACTERIZATION AND REMEDIATION VERIFICATION

PEER REVIEW DRAFT

ATTACHMENT 4 – SOIL GAS and INDOOR AIR

Key definitions for terms and acronyms used in this document:

NREPA:	The Natural Resources and Environmental Protection Act, 1994 PA 451, as amended
Part 201:	Part 201, Environmental Remediation, of NREPA
Part 213:	Part 213, Leaking Underground Storage Tanks, of NREPA
MDEQ	Michigan Department of Environmental Quality
RRD	Remediation and Redevelopment Division
U.S. EPA	United States Environmental Protection Agency
Alpha (Alpha Factor or α)	Key parameter in assessing the significance of subsurface vapor intrusion into indoor air, defined as the concentration of a particular chemical in indoor air divided by its concentration in soil gas at a specified depth beneath the building floor.
AIAC	Acceptable Indoor Air Concentration
ASGSC	Acceptable Soil Gas Screening Concentration
ASTM	American Society for Testing and Materials
atm-m^3/mole	atmosphere per meter cubed/mole
BETX	Benzene/Toluene/Ethylbenzene/Xylenes
bgs	below ground surface
Contamination	Includes hazardous substances that have been released and are present above criteria
CSM	Conceptual Site Model
Criteria or Criterion	Includes the cleanup criteria for Part 201 and the Risk Based Screening Levels (RBSLs) as defined in Part 213 and R 299.5706a(4)
Facility	Includes “facility” as defined by Part 201 and “site” as defined by Part 213
GCs	Gas Chromatographs
GPS	Global Positioning System
GVIIC	Groundwater Volatilization to Indoor air Inhalation Criteria
HVAC	Heating, ventilation or air-conditioning
ICs	Institutional Controls
IRDC	Interim Response Action Designed to meet Criteria
JEM	Johnson and Ettinger Model

Indoor Air Inhalation Criteria	Groundwater Volatilization to Indoor Air Inhalation Criteria (GVIIC) as defined by R 299.5714 and Soil Volatilization to Indoor Air Inhalation Criteria (SVIIC) as defined by R 299.5724
MeCl	Methylene Chloride
MEK	Methyl Ethyl Ketone; 2-Butanone
ml/min	Milliters per minute
NAPL	Non-aqueous phase liquid
NIST	National Institute of Standards and Technology
OM&M	Operation, Maintenance and Monitoring
Op Memo	Operational Memorandum
PAHs	Polynuclear Aromatic Hydrocarbon
PCE	Tetrachloroethene or Perchloroethylene
PID	Photoionization Detector
QA/QC	Quality Assurance/Quality Control
Release	Includes “release” as defined by both Part 201 and Part 213
Response Action	Includes “response activity” as defined in Part 201 and “corrective action” as defined in Part 213
Soil gas	Vapor phase compounds occupying the pore spaces of unsaturated soil
SOP	Standard Operating Procedures
SSD	Sub-slab Depressurization System
SMD	Sub-Membrane Depressurization
SVE	Soil Vapor Extraction
SVIIC	Soil Volatilization to Indoor air Inhalation Criteria
SVOCs	Semi-volatile Organic Compounds
TCA	Trichloroethane
TCE	Trichloroethene
TO-15 or TO-17	U.S. EPA Methods for the determination of Toxic Organic compounds in ambient air
USTs	Underground Storage Tanks
μg/L-vapor	Micrograms per liter
$\mu g/m^3$	Micrograms per meter cubed
Vapor Intrusion	The process by which chemicals in soil or groundwater migrate to indoor air
VOCs	Volatile Organic Compounds

Table of Contents

Section I

1. INTRODUCTION 8

1.1 VOCs 8
1.2 VAPOR INTRUSION 8
1.3 SOIL VAPOR INTRUSION AND HUMAN EXPOSURE 10
1.4 FACTORS AFFECTING SOIL VAPOR MIGRATION AND INTRUSION 10
1.5 FACTORS AFFECTING INDOOR AIR QUALITY 12
1.6 GENERAL APPROACH TO EVALUATING SOIL VAPOR INTRUSION 14
1.7 APPLICABILITY OF GUIDANCE 15
1.7.1 Petroleum Related Facilities, Including Underground Storage Tanks *15*
1.7.2 Dry Cleaners and Industrial Facilities with Non-Petroleum VOCs *15*
1.7.3 Facilities with Releases of Hazardous Substances as Vapors *16*
1.7.4 Criteria and the Vaporization to Indoor Air Pathway *16*
1.7.5 The MDEQ's AIACs and ASGSCs *17*

2. INVESTIGATION OF THE VAPOR INTRUSION PATHWAY 18

2.1 SITES WHERE INVESTIGATION IS APPROPRIATE 19
2.2 PHASE OF A SITE INVESTIGATION IN WHICH TO SAMPLE 19
2.3 TYPES OF SAMPLES 20
2.3.1 Soil Gas or Soil Vapor *20*
2.3.2 Sub-slab Vapor *21*
2.3.3 Flux Chamber *22*
2.3.4 Crawl Space Air *22*
2.3.5 Indoor Air *23*
2.3.6 Outdoor Air *23*
2.4 TIME OF YEAR TO SAMPLE 24
2.4.1 Soil Vapor *24*
2.4.2 Sub-slab Vapor Samples *24*
2.5 NUMBER OF SAMPLING ROUNDS 24
2.6 SAMPLING LOCATIONS 25
2.6.1 Soil Vapor *25*
2.6.2 Sub-slab Vapor *28*
2.6.3 Indoor Air *29*
2.6.4 Outdoor Air *31*

2.7 SAMPLING PROTOCOLS AND CONSIDERATIONS 32
2.7.1 Soil Vapor *32*
2.7.2 Sub-slab Vapor *36*
2.7.3 Indoor Air *38*
2.7.4 Outdoor Air *40*
2.7.5 Tracer Gas *40*
2.7.6 Future Structures *43*
2.8 QUALITY ASSURANCE AND QUALITY CONTROL 43
2.9 ANALYTICAL METHODS 44
2.9.1 Compounds Not Detected by TO-15 or TO-17 ..... *44*
2.9.2 Use of 8260B to Analyze Vapors *45*
2.9.3 Soil Gas Sample Containers *45*
2.9.4 Target Compounds *45*
2.9.5 Indoor Air *46*
2.9.6 Outdoor Air *46*
2.9.7 Field Laboratories and Mobile Gas Chromatographs *46*
2.10 SURVEYS AND PRE-SAMPLING BUILDING PREPARATION FOR INDOOR AIR SAMPLING 47
2.10.1 Pre-Sampling Building Inspection and Preparation *47*
2.10.2 Product Inventory *49*
2.11 ROLE OF MODELING 49

3. DATA EVAULTION AND RECOMMENDATIONS FOR ACTION **50**

3.1 OVERVIEW 51
3.1.1 Nature and Extent of Contamination in All Environmental Media *51*
3.1.2 Factors That Affect Vapor Migration and Intrusion *51*
3.1.3 Sources of Volatile Chemicals *51*
3.1.4 Concentrations of Volatile Chemicals in Ambient Air *52*
3.1.5 Relevant Standards, Criteria, and Guidance Values *52*
3.1.6 Implementation of Remedial Actions *53*
3.1.7 Past, Current, and Future Land Uses *53*
3.2 SAMPLING RESULTS AND RECOMMENDED ACTIONS 54
3.2.1 Soil Vapor *54*
3.2.2 Sub-slab Vapor *55*
3.2.3 Indoor Air *57*
3.2.4 Outdoor Air *59*
3.3 DECISION MATRICES 59
3.3.1 Decision Matrix for Determining Appropriate and Acceptable Sampling Strategies for Assessment of Indoor Air Risk *60*
3.3.2 Sub-slab Results Decision Matrix for Appropriate Response Actions *60*
3.4 EMERGENCY RESPONSE 61
3.5 PARCELS THAT ARE UNDEVELOPED OR CONTAIN UNOCCUPIED BUILDINGS 62

4. VAPOR MITIGATION 62

4.1 METHODS OF MITIGATION 63
4.1.1 Buildings with a Basement Slab or Slab-on-Grade Foundation 63
4.1.2 Buildings with a Crawl Space Foundation 66
4.1.3 Buildings with Dirt Floor Basements 66
4.1.4 Buildings with Multiple Foundation Types 66
4.1.5 Undeveloped Parcels 66
4.2 DESIGN AND INSTALLATION OF MITIGATION SYSTEMS 67
4.2.1 General Recommendations 67
4.2.2 System-specific Recommendations 68
4.2.3 Technical Guidance 70
4.3 POST-MITIGATION OR CONFIRMATION TESTING 71
4.3.1 Sub-slab Depressurization System with Sealing 71
4.3.2 Sub-membrane Depressurization System with Soil Vapor Retarder 73
4.3.3 HVAC Modifications 73
4.3.4 Crawl Space Ventilation and Sealing 74
4.3.5 SVE Systems Designed to Also Mitigate Exposures 74
4.4 OPERATION, MAINTENANCE, AND MONITORING OF MITIGATION SYSTEMS 74
4.4.1 Sub-slab Depressurization Systems and Sub-Membrane Depressurization Systems 74
4.4.2 Other Mitigation Systems 75
4.4.3 Non-routine Maintenance 76
4.5 TERMINATION OF MITIGATION SYSTEM OPERATIONS 76
4.6 MICHIGAN AIR POLLUTION CONTROL RULES 77

5. REFERENCES 78

PREFACE

This Op Memo addresses the appropriate use of and methods for sampling and analysis of soil gas, indoor air for investigation, and other response actions under Part 201 and Part 213 of the NREPA. The requirements of this document are based on obligations established in statutes and rules. Obligations addressed with this document include site characterization (e.g., defining nature and extent of contamination), evaluation of relevant exposure pathways, and compliance with cleanup criteria. The standard approaches the MDEQ has provided with this guidance, if implemented as described, will allow a determination that obligations have satisfactorily been met. Where the approach uses the term *must,* it is a requirement for the approach to be implemented as described, so that the resulting information allows the MDEQ determination that obligations have been met. Other approaches may be proposed to fulfill the necessary obligations, but will require a more thorough MDEQ review of the methods and results to determine if the results satisfactorily address compliance with the obligations. This op memo also presents a reasonable and practical approach to identifying and addressing current and potential human exposures to contaminated subsurface vapors associated with known or suspected volatile chemical contamination. The approach presented herein is analogous to the approach taken when investigating contamination in other environmental media (e.g., groundwater, soil), and addressing corresponding exposure concerns. The vapor intrusion to indoor air pathway has been identified as one of the most complex and tenuous Part 201 pathways. This document is intended to assist in assessing this pathway.

The GVIIC and SVIIC were developed pursuant to Section 20120a and Section 21304a of the NREPA, according to the relevant statutory provisions and the methods and equations presented in R 299.5714 and R 299.5724 (see RRD Op Memo No.1, Part 201 Cleanup Criteria; Part 213 Risk-Based Screening Levels). Information on appropriate facility-specific adjustments for generic indoor air inhalation criteria or the development of facility-specific indoor air inhalation criteria is available in RRD Op Memo No. 1, Attachment 5, Part 201 Groundwater and Soil Volatilization to Indoor Air Inhalation Criteria; Part 213 Tier 1 Groundwater and Soil Volatilization to Indoor Air Inhalation Risk-Based Screening Levels Technical Support Document; and Op Memo No. 1, Part 201 Cleanup Criteria, Part 213 Risk-Based Screening Levels. Soil gas samples, or indoor air samples in conjunction with soil gas samples, may be required in assessing the risk associated with the indoor air inhalation pathway where generic GVIIC and SVIIC are not applicable, a site specific evaluation is being conducted, generic GVIIC or SVIIC is applicable and concentrations are exceeded, or where contaminants have been released and are moving through the soil column in the vapor phase.

Soil gas or indoor air samples may also be appropriate to determine if potential safety or exposure risks of immediate concern exist and whether interim response actions are necessary. When groundwater or soil concentrations exceed indoor air inhalation criteria, indoor air or soil gas sampling may be appropriate to assess initial compliance with due care.

The MDEQ expects that for any structure(s) or proposed structure(s) located within 100 feet horizontally or vertically of where concentrations of contaminants (in soil or groundwater) have

been identified to exceed generic criteria, the immediate as well as long-term risks posed via the indoor air inhalation route must be evaluated. This evaluation could include, in conjunction with soil and/or groundwater sampling, soil gas sampling around and beneath any existing structure. Details regarding the components of an appropriate investigation are provided in Section 2. In order to assist in evaluating whether the generic criteria are applicable at a site, the MDEQ has developed a flowchart to evaluate the applicability of utilizing the generic criteria which can be found in Op Memo No. 1, Part 201 Cleanup Criteria, Part 213 Risk-Based Screening Levels. The MDEQ has also developed a Decision Matrix that summarizes appropriate and acceptable sampling strategies for assessing indoor air risk that can be found in Appendix A. Other action or methods of evaluation may be used, including presumptive risk mitigation methods (e.g., requiring ventilation of or other special precautions for entering the structure; immediate remediation of the soil/soil gas) or performance of facility-specific risk assessments.

This op memo is organized into four sections:

- **Section 1** introduces the concept of soil vapor intrusion, associated human exposure issues, factors affecting soil vapor intrusion, factors affecting indoor air quality, and the general approach recommended to evaluating vapor intrusion.
- **Section 2** provides guidance on collecting appropriate and relevant data that can be used to identify current or potential human exposures.
- **Section 3** discusses how the investigation data are evaluated, recommends actions based on the evaluation, and presents tools that are used when determining appropriate actions to address exposures.
- **Section 4** provides an overview of soil vapor intrusion mitigation methods and basic recommendations pertaining to their selection for use, installation and design, post-mitigation testing, operation, maintenance and monitoring, termination of operation, and annual certification.

This document supersedes all previous RRD guidance on sampling strategies for soil gas or indoor air. Both Part 201 and Part 213 of the NREPA require the identification and mitigation of vapor hazards, which includes fire and explosion as well as inhalation hazards (Sections 20114; 20118; 21307(2)(a) and (3)(b); 21308a(1)(b)(xv); 21309a; 21311a). The State of Michigan programs administered under other parts of the NREPA or federal programs may have requirements in addition to this document. Questions about the appropriate use of soil gas or indoor air monitoring for them should be addressed to staff in those programs. The MDEQ recommends that the guidance be considered anywhere soil vapor intrusion is evaluated in Michigan, whether the evaluation is undertaken voluntarily by a corporation, a municipality, a private citizen, or whether it is performed under Part 201 or Part 213. While soil vapor intrusion can also occur with “naturally-occurring” subsurface gases (e.g., radon), the document discusses soil vapor intrusion in terms of environmental contamination only. This op memo addresses soil vapor intrusion.

Vapor intrusion can also occur through direct volatilization of contaminants from groundwater into indoor air. This can occur when, for example, a basement slab is in

contact with contaminated groundwater, contaminated groundwater enters (floods) a basement or crawl space, or contaminated groundwater enters a sump pit drainage system. In such cases, volatile chemicals can be transferred directly from groundwater to indoor air without the intervening contamination of soil vapor. Although exposures of this nature are not discussed in this guidance, they should be addressed on a site-specific and building-specific basis while following the procedures outlined in Section 2 indoor air samples.

1. INTRODUCTION

1.1 VOCs

A volatile, under R299.5714 and R299.5724, is defined as a hazardous substance in groundwater and soil that has a Henry's Law Constant greater than or equal to 0.00001 atm-m^3/mole. Once in the subsurface, these compounds can become bound to the soil matrix dissolved in groundwater (or soil pore water), and/or exist as a separate, residual phase known as NAPL. Soil, aqueous, and NAPL-phase organics may all be sources of vapors (Weaver, 2005).

The vapor intrusion pathway is always relevant if volatiles are present [R 299.5714(1) and R 299.5724(1)]. An evaluation is always necessary where the pathway is relevant (i.e., volatiles present); however, there may be circumstances where application of the generic GVIIC or SVIIC may not be appropriate based on facility or site-specific conditions [Section 1.7.4 and Op Memo No. 1, Part 201 Cleanup Criteria, Part 213 Risk-Based Screening Levels].

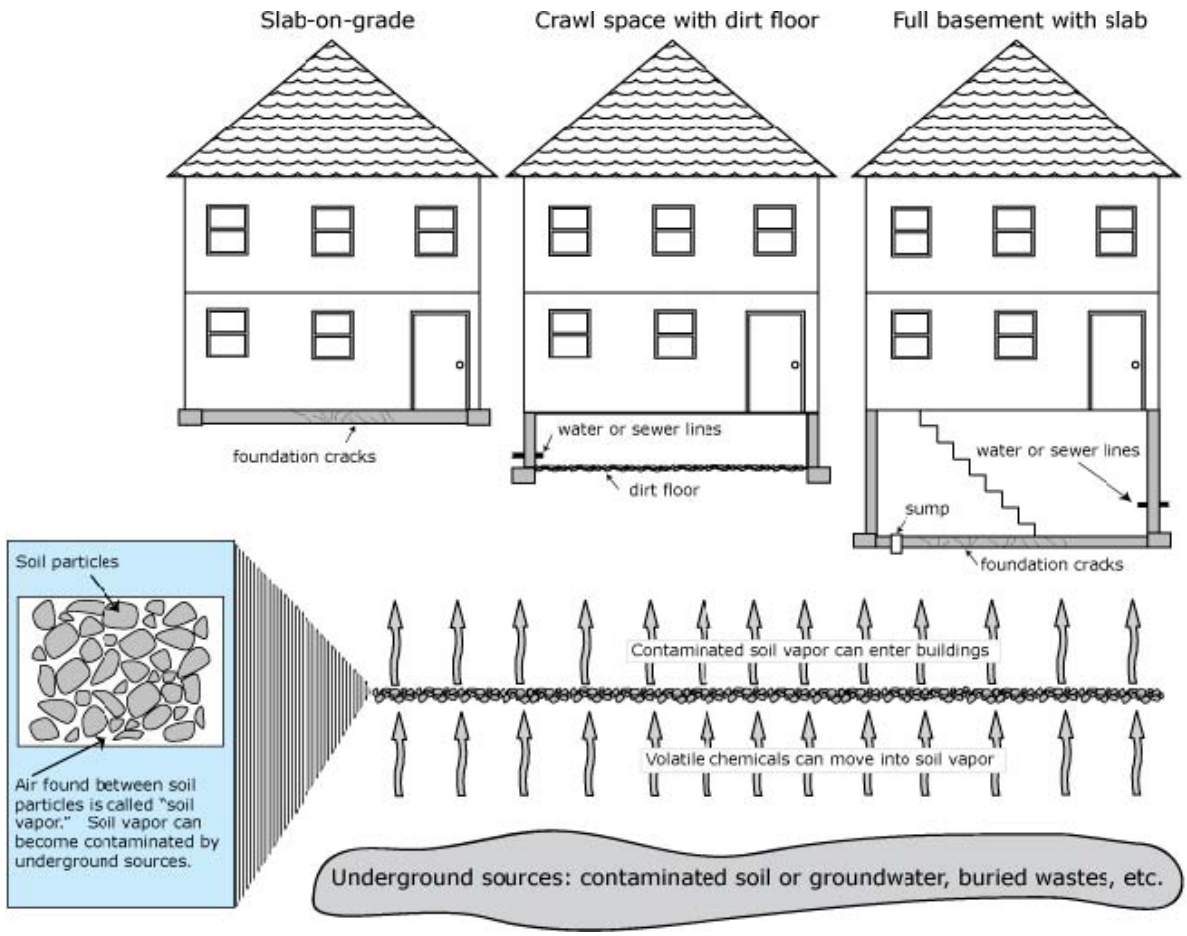
The VOCs in working or living spaces can be an immediate threat as a source of explosive vapors or, more insidiously, as a long-term source for exposures to potential carcinogenic or toxic compounds. These sources of vapors can be either introduced by products that are physically brought into the building, or by a source of organic vapors outside the structure, including in the subsurface. Indoor air samples, when collected, reflect only the conditions that are occurring during the sample period at the point of the sample collection. The source of vapors that are regulated under Part 201 and Part 213 are vapors that originate at a regulated facility from contamination in the subsurface. Potential sources of vapors or source of a release that results in vapors include landfills, factories, manufacturing centers, dry cleaners, and gas stations among others. It is these vapors that Part 201 and Part 213 regulate.

1.2 Vapor Intrusion

The phrase "vapor intrusion" refers to the process by which volatile chemicals migrate from a subsurface source into the indoor air of buildings. Soil vapor, also referred to as soil gas, is the air found in the pore spaces between soil particles (Figure 1.1). Primarily because of a difference between interior and exterior pressures, soil vapor can enter a building through cracks, perforations in slabs, basement floors, walls, through openings around sump pumps, or where pipes and electrical wires go through the foundation. For example, HVAC systems and/or the operation of large mechanical appliances (e.g., exhaust fans, dryers), may create a

negative pressure that can draw soil vapor into the building. Vapor intrusion is similar to how radon gas enters buildings from the subsurface.

Figure 1.1
Generalized diagram of soil vapor intrusion



Soil vapor can become contaminated when chemicals evaporate from subsurface sources. Volatile chemicals include VOCs, some SVOCs, and some inorganic substances such as elemental mercury.

Subsurface sources of volatile chemicals can include the following:

a) Groundwater or soil that contains volatile chemicals,
b) NAPL,
c) Buried wastes, and
d) Underground storage tanks or drums.

If soil vapor is contaminated and enters a building, the indoor air quality may be affected. When contaminated vapors are present next to or under the foundation of a building, vapor intrusion is possible, even when soil and groundwater samples do not indicate any level of impact. Soil vapor can enter a building whether the building is old or new, or whether it is on a slab, has a crawl space, or a basement (Figure 1.1). However, the subsurface source of the contaminated vapor (e.g., contaminated soil, groundwater, NAPL, free phase, saturated soil), does not need to be directly beneath a structure to contaminate the vapor immediately beneath the building's foundation (as suggested in Figure 1.1).

The U.S. EPA (U.S. EPA, 2002) identified a distance of 100 feet horizontally or vertically from concentrations of contaminants (in soil or groundwater), that necessitates evaluation of the immediate, as well as long-term risks, posed by the indoor air inhalation pathway. This distance by the U.S. EPA was based primarily on professional judgment and practical considerations as well as empirical data. However, based on theoretical considerations, it is known that this distance criterion should consider the depth to the vapor source, the vapor source strength, the indoor-air target levels, and the local geology (Abreu and Johnson, 2004; Lowell and Eklund, 2004). Thus, the 100-foot distance might not be protective at every site.

1.3 Soil Vapor Intrusion and Human Exposure

Humans can be exposed to contaminated soil vapor when the vapor is drawn into the building [Section 1.1] and mixed with the indoor air. Inhalation is the primary route of exposure, or the manner in which the volatile chemicals, once in the indoor air, actually enter the body.

Exposure to a volatile chemical due to vapor intrusion does not necessarily mean that health effects will immediately occur. Whether or not a person experiences health effects depends on several factors, including the length of exposure (short-term or acute versus long-term or chronic), the amount of exposure (i.e., dose), the frequency of exposure, the toxicity of the volatile chemical, and the individual's sensitivity to the chemical.

1.4 Factors Affecting Soil Vapor Migration and Intrusion

Studies have also shown that soil gas concentrations may vary at different locations beneath buildings (Laubacher et al., 1997). Predicting the extent of soil vapor contamination from soil or groundwater contamination, as well as the potential for human exposure from soil vapor intrusion into buildings, is complicated by numerous factors that can affect soil vapor migration and intrusion. For example, soil vapor contaminant plumes may not mimic groundwater contaminant plumes, since different factors affect the migration pattern of each medium. In addition to the operation of HVAC systems, the operation of kitchen vents in restaurants, or of elevators in buildings, may also induce pressure gradients that result in the migration of vapor-phase contaminants away from a groundwater source of vapors and toward these buildings. This is similar to when the pumping of production wells or water supply wells draws contaminated groundwater away from its natural flow path. Buildings and/or other surface covers, like a parking lot, may also affect the ability of vapor to attenuate. Factors that can affect soil vapor migration and intrusion generally fall into two categories: environmental and

building factors. Additional information regarding environmental factors is provided in Table 1.1, and information on building factors is provided in Table 1.2.

Table 1.1 Environmental factors that may affect soil vapor intrusion

Environmental Factors	Description
Soil conditions	Generally, dry, coarse-grained soils facilitate the migration of subsurface vapors and wet, fine-grained or highly organic soils retard migration.
Volatile chemical concentrations	The potential for vapor intrusion generally increases with increasing concentrations of volatile chemicals in groundwater or subsurface soils, as well as with the presence of NAPL.
Source location	The potential for vapor intrusion generally decreases with increasing distance between the subsurface source of vapor contamination and overlying buildings. For example, the potential for vapor intrusion associated with contaminated groundwater decreases with increasing depth to groundwater.
Groundwater conditions	Volatile chemicals dissolved in groundwater may off-gas to the vadose zone from the surface of the water table. If contaminated groundwater is overlain by clean water (upper versus lower aquifer systems or significant downward groundwater gradients), then vapor phase migration or partitioning of the volatile chemicals is unlikely. Additionally, fluctuations in the groundwater table may results in contaminant smear zones. The "smear zone" is the area of subsurface soil contamination within the range of depths where the water table fluctuates. Chemicals floating on top of the water table, such as petroleum components, can sorb onto soils within this zone as the water table fluctuates. Sorption of chemicals can influence their gaseous and aqueous phase diffusion in the subsurface, and ultimately the rate at which they migrate.
Surface confining layer	A surface confining layer (e.g., frost layer, pavement or buildings) may temporarily or permanently retard the migration of subsurface vapors to outdoor air. Confining layers can also prevent rainfall from reaching subsurface soils, creating relatively dry soils that further increase the potential for soil vapor migration.
Fractures in bedrock and/or tight clay soils	Fractures in bedrock and desiccation fractures in clay can increase the potential for vapor intrusion beyond that expected for the bulk, unfractured bedrock or clay matrix by facilitating vapor migration (in horizontal and vertical directions) and movement of contaminated groundwater along spaces between fractures.
Underground conduits	Underground conduits (e.g., sewer and utility lines, drains or tree roots, septic systems) with highly permeable bedding materials relative to native materials can serve as preferential pathways for vapor migration due to relatively low resistance to flow.
Weather conditions	Wind and barometric pressure changes and thermal differences between air and surrounding soils may induce pressure gradients that affect soil vapor intrusion.
Biodegradation processes	Depending upon environmental conditions (e.g., soil moisture, oxygen levels, pH, mineral nutrients, organic compounds, and temperature), the presence of appropriate microbial populations, and the degradability of the volatile chemical of concern, biodegradation in the subsurface may reduce the potential for vapor intrusion. For example, readily biodegradable chemicals in soil vapor may not migrate a significant distance from a source area while less degradable chemicals may travel farther.

From NYSDOH, 2006

Table 1.2 Building factors that may affect vapor intrusion

Building Factor	Description
Operation of HVAC systems, fireplaces, and mechanical equipment (e.g., clothes dryers or exhaust fans/vents)	Operation may create a pressure differential between the building or indoor air and the surrounding soil that induces or retards the migration of vapor-phase contaminants toward and into the building. Vapor intrusion can be enhanced as the air vented outside is replaced.
Heated building	When buildings are closed up and heated, a difference in temperature between the inside and outdoor air induces a stack effect, venting warm air from higher floors to the outside. Vapor intrusion can be enhanced as the air is replaced in the lower parts of the building.
Air exchange rates	The rate at which outdoor air replenishes indoor air may affect vapor migration into a building as well the indoor air quality. For example, newer construction is typically designed to limit the exchange of air with the outside environment. This may result in the accumulation of vapors within a building.
Foundation type	Earthen floors and fieldstone walls may serve as preferential pathways for vapor intrusion.
Foundation integrity	Expansion joints or cold joints, wall cracks, or block wall cavities may serve as preferential pathways for vapor intrusion.
Subsurface features that penetrate the building's foundation	Foundation perforations for subsurface features (e.g., electrical, gas, sewer or water utility pipes, sumps, and drains) may serve as a preferential pathway for vapor intrusion.

From NYSDH, 2006

1.5 Factors Affecting Indoor Air Quality

Chemicals are a part of our everyday life. They are found in the household products we use and in items we bring into our homes. As such, chemicals are found in indoor air of homes not affected by intrusion of contaminated soil vapor. Examples of alternate sources of volatile chemicals in indoor air are given in Table 1.3. Similarly, volatile chemicals can be in the outdoor air that enters a home or place of business. Certain commercial and industrial facilities, such as gasoline stations, dry cleaners, and vehicle exhaust are examples of possible sources of volatile chemicals in outdoor air. Although indoor air sampling may provide direct evidence of building occupant inhalation, exposures provide a basis for identification and mitigation of such exposures as required by due care. This approach will not distinguish the exposure resulting from subsurface vapor intrusion, and may include contributions from indoor air sources (products used or stored); or ambient (outdoor) air concentrations.

This is, in part, why the MDEQ has identified a preference for soil vapor sampling over indoor air sampling. Many household consumer products, furnishings, building materials, and household activities result in emissions of hazardous substances that may add to the concentration and number of chemicals in the indoor air. Such hazardous substance emissions could contribute to

exceedances of their respective AIACs. The indoor air in homes in urban areas also may be affected by anthropogenically elevated ambient levels of hazardous substances in outdoor air. Concentrations are also influenced by temporal (seasonal) variations due to meteorological conditions, building operations related to heating and air conditioning, activities and chemical use, including household chemical use, by any occupants. Each of these sources may introduce volatile chemicals into the indoor environment at concentrations sufficient to pose an unacceptable risk, but not represent a result of a release that is regulated under Part 201 or Part 213.

The MDEQ has reviewed the available methods for indoor air sampling as provided for in R 299.5714(5) and R 299.5724(5) and has determined that available methods cannot reliably produce indoor air concentration measurements that are more representative of in-situ conditions (soil gas, groundwater and soil contamination, and the risks posed by that contamination) than groundwater or soil samples. Therefore, indoor air sampling alone cannot be approved as a method to demonstrate compliance with the groundwater and soil indoor air

Table 1.3 Alternate sources of volatile chemicals in indoor air

Source	Description
Outdoor air	Outdoor sources of pollution can affect indoor air quality due to the exchange of outdoor and indoor air in buildings through natural ventilation, mechanical ventilation or infiltration. Outdoor sources of volatile compounds include automobiles, lawn mowers, oil storage tanks, dry cleaners, gasoline stations, industrial facilities, etc.
Attached or underground garages	Volatile chemicals from sources stored in the garage (e.g., automobiles, lawn mowers, oil storage tanks, gasoline containers, etc.) can affect indoor air quality due to the exchange of air between the garage and indoor space.
Off-gassing	Volatile chemicals may off-gas from building materials (e.g., adhesives or caulk), furnishings (e.g., new carpets or furniture), recently dry-cleaned clothing, or areas (such as floors or walls) contaminated by historical use of volatile chemicals in a building. Volatile chemicals may also off-gas from contaminated groundwater that infiltrates into the basement (e.g., at a sump) or during the use of contaminated domestic well water (e.g., at a tap or in a shower).
Household products	Household products include, but are not limited to, cleaners, mothballs, cigarette smoke, paints, paint strippers and thinners, air fresheners, lubricants, glues, solvents, pesticides, fuel oil storage, and gasoline storage.
Occupant activities	For example, in non-residential settings, the use of volatile chemicals in industrial or commercial processes or in products used for building maintenance. In residential settings, the use of products containing volatile chemicals for hobbies (e.g., glues, paints, etc.) or home businesses. People working at industrial or commercial facilities where volatile chemicals are used may bring the chemicals into their home on their clothing.
Indoor emissions	These include, but are not limited to, combustion products from gas, oil and wood heating systems that are vented outside improperly, as well as emissions from industrial process equipment and operations.

From NYSDH, 2006

inhalation criteria. Monitoring the health risks of vapor intrusion at the receptor does not provide the information necessary to assess the source of contamination and identify needed response actions to provide reliable long-term protection from unacceptable exposures.

1.6 General Approach to Evaluating Soil Vapor Intrusion

Since no two sites are exactly alike, the approach to evaluating soil vapor intrusion is dependent upon site-specific conditions and a CSM. A thorough understanding of the site, including its history of use, characteristics (e.g., geology, geography, identified environmental contamination), and potentially exposed populations, is required to develop an investigation plan.

Existing information should be reviewed to determine what data are available and what additional data should be collected. In addition, factors affecting soil vapor migration, intrusion, and indoor air quality are also considered when both conducting an investigation [Section 2] and evaluating the results [Section 3].

This data gathering and review process should be repeated until each of the following questions can be answered:

1) Are subsurface vapors contaminated (i.e., soil vapor as defined in Section 1.1, including vapors located immediately beneath the foundation or slab of a building)? If so, what are the nature and extent of contamination? What is/are the source(s) of the contamination?
2) What are the current and potential exposures to contaminated subsurface vapors via soil vapor intrusion?
3) What actions, if any, should be taken to prevent or mitigate exposures related to soil vapor intrusion and to remediate subsurface vapor contamination?

When determining what actions, if any, are appropriate to mitigate current or prevent future human exposures, all information known about a site is considered because each site presents its own unique set of circumstances. This information includes, but is not limited to, the nature and extent of the contamination in all environmental media, factors affecting vapor migration and intrusion, current and future site uses, off-site land uses, presence of alternate sources of volatile chemicals, and completed or proposed remedial actions.

Actions taken to minimize or prevent vapor intrusion, or exposures from vapor intrusion typically do not preclude the site from being used for a desired purpose or from being developed. If appropriate, mitigation systems can be installed at existing buildings or installed during the construction of new buildings. In many cases, installation of mitigation systems on new buildings may be a prudent, proactive action. The costs associated with installing a system at the time of a building's construction are often considerably less than the costs associated with retrofitting a system to the building after construction is completed.

1.7 Applicability of Guidance

The guidance should be used when evaluating soil vapor intrusion at chlorinated and non-chlorinated volatile chemical sites, including petroleum hydrocarbon sites and manufactured gas plant sites. While the likelihood for exposures related to soil vapor intrusion may differ between sites due to site-specific conditions, chemical-specific properties, the extent of volatile chemical contamination and the nature of the contamination, these factors should be considered when developing the conceptual site model and implementing an investigation. This guidance is intended to assist in the work necessary to comply with the obligations to assess this pathway under Part 201 and Part 213

1.7.1 Petroleum Related Facilities, Including Underground Storage Tanks

Petroleum products, such as gasoline and diesel, are complex mixtures containing a wide variety of different hydrocarbons. Subsurface sources can include leakage from USTs, fill ports, pipelines, and various pipe fittings. Although soil gas surveys may be useful in evaluating risks from volatile hydrocarbons such as BTEX, soil gas is not an appropriate investigatory methodology for nonvolatile petroleum hydrocarbons such as oils and most SVOCs or PAHs. Therefore, soil gas may not be useful for assessing a release of heavier fuels (e.g., diesel and fuel oil), or oils; however, that does not alleviate the need to address these situations.

In situations that contaminants are present that cannot be analyzed through appropriate soil gas methods (Op Memo No. 2), alternate investigative methods may be proposed including utilizing a combination of methods. This may be a concurrent collection and analysis of a sub-slab, indoor air samples, and the use of marker compounds that can be identified in both media.

1.7.2 Dry Cleaners and Industrial Facilities with Non-Petroleum VOCs

At industrial facilities, a variety of contaminants, conditions, and potential vapor sources can exist. Many industrial facilities contain above ground solvent sources such as degreasers, clarifiers, storage tanks, ink presses, or spray booths, which can leak into the vadose zone. Subsurface sources can include leakage from drains, sumps, pipelines, and manufacturing lines. Consequently, a soil gas survey at an industrial facility should be performed only after a thorough reconnaissance has been performed to establish the potential vapor sources and types of contamination.

At dry cleaner facilities, soil gas contamination commonly exists under the washer unit, and soil contamination with corresponding soil gas contamination, commonly exists near liquid release sources such as sumps, drains, storage areas, and other disposal areas. It is also possible for some contaminates like PCE, that have a high Henry's Law Constant, to be present as a vapor release without observing any impact to soil or groundwater.

Chemicals associated with industrial facilities vary, but may include chlorinated solvents and degreasers, such as methylene chloride, TCA, TCE, PCE, acetone, and MEK. Not all contaminants at a facility may be detectable by soil gas methods depending upon their gas

pressures. At dry cleaner facilities, the primary contaminant is PCE and its breakdown products: TCE, various dichloroethylene, and vinyl chloride. When conducting a due care assessment, the detection limits, calibration procedures, and other QA/QC criteria should comply with all MDEQ approved analytical sampling methodology (Op Memo No. 2).

1.7.3 Facilities with Releases of Hazardous Substances as Vapors

In some cases, the GVIIC and SVIIC are not protective due to facility-specific or contaminant-specific concerns. In situations where these conditions have been identified, additional requirements may be established for response actions (R 299.5532(9)). Situations that will require additional response actions include hazardous substances that have been released via a vapor leak or exist as a subsurface vapor cloud.

Vapor leaks from storage tanks and associated piping including vent pipes, pipe joints, vapor recovery lines, and tank bungs, are known to occur even in situations where there is no apparent loss of product from the storage system. These vapor leaks can result in soil gas contamination and may contribute to soil or groundwater contamination. This soil gas contamination can exist with no corresponding detectable soil or groundwater contamination. For instance, due to the high vapor pressures and high vapor densities of chlorinated compounds (e.g. PCE and TCE), vapors may emanate from containers or pipes holding these compounds (in either gaseous or liquid phase) which can collect on the floor, penetrate through the slab, and create a zone of contaminated vapor in the vadose zone.

When vapor releases have been confirmed or are suspected at a facility, the collection of soil gas samples in addition to soil and/or groundwater samples will be required to adequately evaluate the exposure pathways. In most cases, this will require soil gas samples to be collected from locations alongside or beneath any structures as well as across the facility.

1.7.4 Criteria and the Vaporization to Indoor Air Pathway

R 299.5714 and R 299.5724 state that indoor inhalation of hazardous substance vapors volatilizing to indoor air from soil or groundwater shall be considered a reasonable and relevant exposure pathway.

For facilities with a source of vapors present in the groundwater, R 299.514(2) states that the generic GVIIC shall not apply and a site-specific evaluation of indoor inhalation risks shall be conducted if:

a) There is a structure present or planned to be constructed at the facility which does not have a concrete block or poured concrete floor and walls.
b) The highest water table elevation of a contaminated saturated zone at the facility, considering seasonal variation, is within three meters of the ground surface; or
c) There is a sump present that is not completely isolated from the surrounding soil by its materials of construction, or there is other direct entry of contaminated groundwater into the basement.

For facilities with a source of vapors in the soil, R 299.574(2) states that the generic criteria shall not apply, and a site-specific evaluation of indoor inhalation risks shall be conducted if:

a) There is a structure present or planned to be constructed at the facility which does not have a concrete block or poured concrete floor and walls; or
b) There is a sump present that is not completely isolated from the surrounding soil by its materials of construction.

One of the equations identified in R 299.5714 and R 299.5724 is commonly referred to as the JEM (as further described in Johnson and Ettinger, 1991). In the JEM, the U.S. EPA (U.S. EPA, 2002) and others (Weaver and Tillman, 2005, Johnson, 2002, etc.) have identified several conditions that must be representative of the conceptual site model in order for concentrations that are generated through its use, to be representative of actual conditions. As a result, at Part 201 or Part 213 sites of environmental contamination, concentrations generated by the use of the JEM are not representative, and therefore, the generic criteria would not be protective of human health. The following conditions, as identified by the U.S. EPA, must be present in order to utilize the JEM.

- The contaminant is homogeneously distributed.
- Soil is homogeneous such that the effective diffusion coefficient is constant.
- Contaminant loss from leaching downward does not occur.
- Contaminant concentration at the interface between the soil particle surface and soil pore air space is zero (i.e., boundary layer resistance is zero).
- Convective vapor flow near the building foundation is uniform.
- Convective vapor flow rates decrease with increasing distance between the contaminant source and the building.
- Contaminant vapors enter the building through openings in the walls and foundation at or below grade.
- Both the building ventilation rate and the difference in pressure between the building interior and the surrounding soil are constant.
- All contaminant vapors directly below the building will enter the building.
- The building contains no other contaminant sources or sinks, and contaminant vapor dispersion is instantaneous and homogeneous.
- The contaminant is not present in a NAPL or in concentrations that indicate C_{sat} conditions or situations where a contaminant is part of a mixture that is present above the effective solubility.

Additional information regarding the JEM can be found in Op Memo No. 1.

1.7.5 The MDEQ's AIACs and ASGSCs

An evaluation of the volatilization to indoor air pathway is always necessary when the pathway is relevant; however, there may be circumstances where generic GVIIC or SVIIC are not appropriate to use to evaluate the vapor intrusion risks based on facility or site-specific

conditions or limitations of the model [Section 1.7.4 and Op Memo No. 1]. R 299.5714(5) and R 299.5724(5) state that the MDEQ may approve of alternate methods to demonstrate compliance with the criteria for this exposure pathway. These rules also specifically identify the use of soil gas concentrations as a way to fulfill the demonstration for compliance. Therefore, the MDEQ has developed the ASGSCs to further assist in the evaluation of this pathway. A site specific evaluation utilizing other methods and models may be proposed to the MDEQ; however, it will require the collection of data and soil parameters that are usually not collected as part of a routine investigation. In addition, the flowchart in Op Memo No. 1, Part 201 Cleanup Criteria, Part 213 Risk-Based Screening Levels is designed to assist in determining whether modification to the JEM is appropriate.

A key parameter in assessing the significance of subsurface vapors, the concentrations required for intrusion into indoor air, and in the development of the ASGSCs is the vapor attenuation coefficient ("alpha" or α). The alpha is defined as the concentration of a particular chemical in indoor air divided by its concentration in soil gas at a specified depth beneath the building floor (Berry-Spark, 2004). It is commonly referred to as a numerical constant (unitless) either derived empirically, modeled, or estimated to predict a concentration in soil gas that may cause impacts to indoor air above acceptable health-based indoor air screening levels.

When using epically derived data, the alpha can be represented mathematically by:

$$\alpha_{sg} = C_{indoor}/C_{soil\ gas}$$

The U.S. EPA (U.S. EPA, 2002); established a dataset that contains multiple sites across the United States. These sites have samples where concentrations of various VOCs have been detected in the indoor air as well as the soil vapor. Utilizing the equation above and the data available by the database, an empirically derived alpha was established by the MDEQ. By utilizing these alphas, the MDEQ was then able to establish the ASGSCs identified in Appendix B. This was done by substituting the AIACs for C_{indoor}, applying the calculated alphas, and then solving for $C_{soil\ gas}$ which represents a concentration in soil vapor that is not likely to represent a health risk.

Vapor concentrations must be compared to the ASGSCs on a point-by-point basis. Statistical comparison of the data to the ASGSCs is not practical. Each exceedance must be addressed, especially if the acute indoor air concentrations are expected to be exceeded.

2. INVESTIGATION OF THE VAPOR INTRUSION PATHWAY

Soil vapor is an environmental medium that needs to be assessed like groundwater and soil. In limited circumstances, the MDEQ's generic criteria apply, and the vapor intrusion pathway may be assessed through soil and groundwater samples. However, at most sites, the generic criteria do not apply. This is a result of the rules (R 299.5714 and R 299.5724) or site specific conditions that exceed the limitations of the JEM (Op Memo No. 1). This includes when source concentrations have been identified above C_{sat} or when free phase contamination is present. In most cases where the generic criteria do not apply, an assessment of the vapors may be

conducted during the investigation of the site to evaluate the vaporization to indoor air. This section provides guidance on collecting appropriate and relevant data to identify current or potential human exposures to contaminated subsurface vapors associated with a site. As discussed in Section 1, no two sites are exactly alike. Site-specific and/or building-specific conditions may warrant modifying the recommendations herein. Therefore, guidance provided in this section is presented in terms of general steps and strategies that should be applied when approaching an investigation to assess this pathway. A conceptual site model is an important tool and should be included in any work plan. The conceptual site model should guide the data collection program, and it may not be appropriate to collect data in the same locations or using the same methods for sites with significantly different conditions (McAlary, 2003).

2.1 Sites Where Investigation is Appropriate

Although the level of investigation may vary, the pathway must be evaluated when the pathway is relevant (Section 1.7.5) and would include any site with the following:

a) An existing subsurface vapor source (e.g., on the basis of preliminary environmental sampling) or likely subsurface source (e.g., on the basis of known previous land uses), of volatile chemicals, or
b) Existing buildings or the possibility that buildings may be constructed near a subsurface source of vapors.

Depending on the site conditions and the initial evaluation of concentrations, this evaluation may determine the initial implement of a presumptive mitigation system to address the pathway as either an interim response action, or even potentially as an IRDC.

2.2 Phase of a Site Investigation in which to Sample

There is no single phase (e.g., preliminary site characterization or remedial investigation) of a site investigation during which sampling to evaluate the soil vapor intrusion pathway is required. Initiation of investigation activities for this specific purpose should be determined on a site-by-site basis on whether the pathway is relevant. When exposures due to soil vapor intrusion appear likely, evaluation of this exposure pathway should not be delayed.

If the locations of likely source areas are reasonably known, sampling earlier during the investigation of a site, rather than later, is recommended because of the iterative nature of the sampling process. However, if current site conditions are not well defined, then sampling after contamination in other environmental media (e.g., groundwater and soil) has been characterized may be considered. In the latter scenario, groundwater, soil, and other site information that is available in the CSM may be used to guide an investigation of the soil vapor intrusion pathway, such as selecting locations for subsurface vapor samples based on likely migration pathways and source areas. At a minimum, depth to groundwater and soil stratigraphy should be identified prior to collecting soil vapor samples.

2.3 Types of Samples

The following are types of samples that are collected to investigate the soil vapor intrusion pathway:

1) Subsurface vapor samples, including:
   a) *Soil gas* samples (i.e., soil vapor samples collected at depth, which may include samples beneath the foundation or slab of a building collected at a depth greater than three feet below the foundation) and;
   b) *Sub-slab vapor* samples (i.e., soil vapor samples immediately beneath the foundation or slab of a building),
2) Flux chamber samples,
3) Crawl space air samples,
4) Indoor air samples, and
5) Ambient air samples.

The types of samples that should be collected depend upon the objective(s) of the sampling, as described below.

2.3.1 Soil Gas or Soil Vapor

Soil gas data can be used, in most cases, to evaluate vapor intrusion to indoor air when the generic criteria do not apply. Soil gas data are recommended over other data, such as soil matrix and groundwater data, because soil gas data represent a direct measurement of the contaminant that will migrate into indoor air. While partitioning equations are readily available for soil and groundwater data, using them increases the uncertainty in evaluating vapor intrusion. Hence, soil gas is the preferred contaminant data to use for calculating the risk from the vapor intrusion pathway. This preference for soil gas data to evaluate vapor intrusion is shared by the U.S. EPA (2002) and Johnson and Deize-Abreu (2003). It may be necessary to collect soil gas samples at multiple distinct time intervals to compensate for the effects of weather, such as recent rainfall or barometric fluctuations. Ideally, for vapor intrusion sites, permanent vadose monitoring points for sample collection should be installed to evaluate the long-term behavior of contaminated soil gas.

Soil gas can be used for a number of purposes, including:

- **Initial site screening**, where the objective is to assess if (VOCs) are present.
- **Site assessment/characterization**, where the objective is to assess the source, extent, and magnitude of impacted soil, groundwater and/or vapor.
- **Due care,** where the objective is to protect the occupants and public health.
- **Remediation and post-remediation monitoring**, where the objective is to assess remediation progress or completion.
- **Ongoing monitoring** for risk assessment, remediation monitoring, landfill gas monitoring, and background methane monitoring.

Soil gas samples are often collected before sub-slab vapor and/or indoor air samples to help identify areas, buildings, or groups of buildings that need additional sampling. *Soil vapor* samples are not the same as *soil* samples. It may be possible to assess the potential for vapor intrusion with a soil gas sample outside of a structure if the following conditions are present:

- The geology does not contain preferential pathways.
- The CSM allows for a uniform path of the vapor.
- Samples are able to be collected at a depth >eight feet below grade and five feet below the lowest point of the structure that minimize potential affects of any structure or atmospheric effects or;
- The location of the vapor sample is immediately above the vapor source.

Soil gas samples when collected directly above a vapor source, whether it be groundwater, soil, or free phase contamination, and at depths in the subsurface (>eight feet bgs), that are not influenced by atmospheric or site conditions (including oxygen exchange), are the most reliable. As soil gas samples are collected shallower and closer to a structure, the more variability is expected to be present in the sampling results. As the potential for variability increases, the numbers of sampling events also increase in order to establish any long-term compliance determinations.

Based upon the specific site conditions, to the extent possible, soil gas samples should be collected at depths and flow rates chosen to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface. This ensures that consistent and representative samples are collected. Soil gas samples collected at depths greater than five feet below the structure and closer to the source of the vapors has been shown to produce more consistent and repeatable data for decision making. Detailed information about sampling considerations is found in Section 2.5.

2.3.2 Sub-slab Vapor

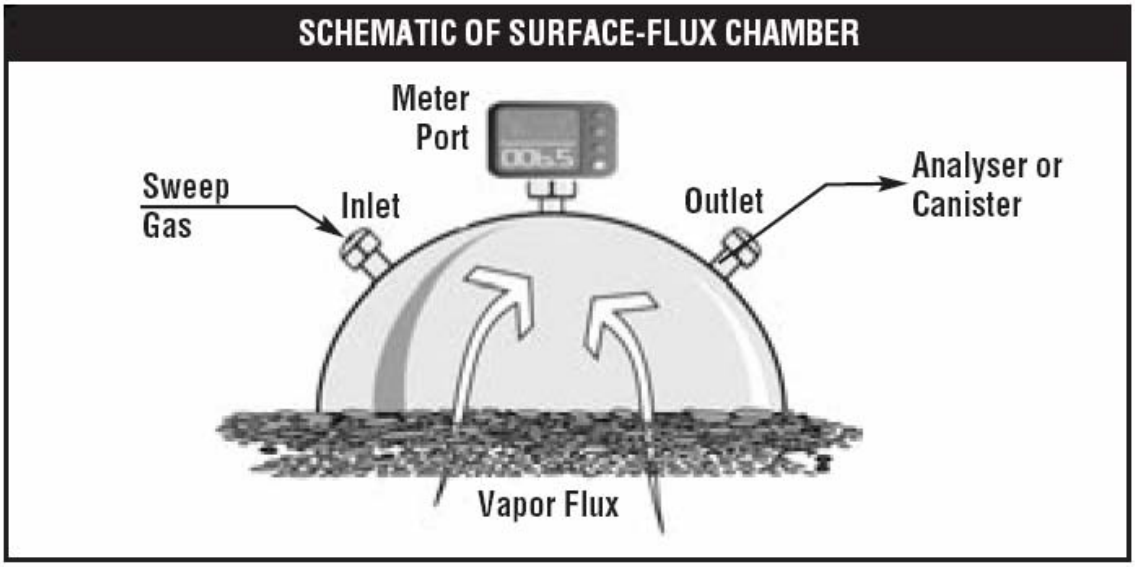
Sub-slab samples are soil vapor samples that are collected immediately below the flooring in the lowest level of a structure. Sub-slab samples, like soil gas samples represent a direct measurement of the contaminant that may migrate into indoor air; however, they often experience a greater variability than soil gas samples collected deeper in the soil column, nearer the vapor source. As stated in Section 2.2.1, sub-slab samples, like soil vapor samples are collected to determine whether this environmental medium is contaminated, characterizes the nature and extent of that contamination, and identifies possible sources of that contamination.

At sites that warrant shallower soil vapor samples to be collected, conditions are often present that identify volatile chemicals in sub-slab vapor samples substantially higher (e.g., by a factor of 100 or more) than concentrations found in nearby soil vapor samples (e.g., collected at five feet or less below grade near the building). This may be due to differences in factors such as soil moisture content, pressure gradients, and factors that influence biodegradation, attenuation, and dispersion that differ under buildings due to a “capping” effect caused by the structure.

2.3.3 Flux Chamber

Flux chambers provide a direct measurement of the subsurface contaminant flux. Flux chambers are not applicable to every type of structure or site. For example, the use of chambers in basements or any other subterranean enclosure is not practical, because the four walls of the basement could also be an actual source of the vapor flux (Hartman, 2003) and there may also be an inability to place chambers in the location of highest vapor intrusion (e.g. the walls of a basement). Also, a flux chamber that results from undeveloped lots may or may not be representative of fluxes into a future structure. On one hand, the measured flux could be over-estimated because there is no building foundation impeding the flux; on the other hand, the measured flux could be under-estimated for reasons such as the lack of pressure induced advective flow caused by the heating or ventilation system in the overlying structure (Hartman, 2003). A flux chamber is depicted in Figure 2.1.

Figure 2.1



Hartman, 2003

In limited circumstances, flux chambers may play an important part during a site investigation when site specific criteria are being generated. They may also be important in assessing a volatilization pathway during certain remedial actions or obligations as a result of due care obligations. Discussion on the approach and use of flux chambers should be submitted and approved by the MDEQ on a case-by-case basis.

2.3.4 Crawl Space Air

Similar to sub-slab vapor samples, crawl space air samples are collected to characterize the nature and extent of contamination immediately beneath a building with a crawl space foundation. Crawl space air sampling results are used in conjunction with indoor air and

outdoor air sampling results when evaluating *current* human exposures, and the potential for *future* human exposures (e.g., if the structural integrity of the building changes or the use of the building changes).

2.3.5 Indoor Air

Indoor air samples are collected to characterize the existence of exposures to air within a building, including those with earthen floors. Indoor air sampling results are used when evaluating the following:

a) *Current* human exposures,
b) Site-specific attenuation factors (e.g., the ratio of indoor air to sub-slab vapor concentrations), and
c) Contaminants that cannot be reliably detected in soil gas samples.

Indoor air samples are often collected after subsurface vapor characterization and other environmental sampling (e.g., soil and groundwater characterization) indicate they are warranted. When indoor air samples are collected, concurrent sub-slab vapor, crawl space air (if applicable), and outdoor air samples are collected to evaluate the indoor air results appropriately. However, indoor air and outdoor air samples, without sub-slab vapor samples, may be collected when confirming the effectiveness of a mitigation system (Section 4). In addition, site-specific situations may warrant collecting indoor air samples prior to characterizing subsurface vapors to examine immediate inhalation hazards.

Examples of such situations may include, but are not limited to, the following:

a) Response to a spill event to qualitatively and/or quantitatively characterize the contamination;
b) High readings obtained in a building when screening with field equipment (e.g., a PID, an organic vapor analyzer, or an explosimeter) with the source unknown;
c) Significant odors present and the source needs to be characterized; or
d) Groundwater beneath the building is contaminated, and the building is prone to groundwater intrusion or flooding (e.g., sump pit overflows), and subsurface vapor sampling is not feasible. In these situations, the collection of water samples from the sump may also be appropriate.

Results of indoor air samples alone cannot be used to demonstrate compliance with the vaporization pathway.

2.3.6 Outdoor Air

Outdoor air samples are collected to characterize site-specific outdoor air conditions. Outdoor air samples should be collected simultaneously with indoor air samples to evaluate the potential influence, if any, of outdoor air on the indoor air sampled. Outdoor air samples may also be collected concurrently with soil vapor samples to identify potential outdoor air interferences

associated with infiltration of outdoor air into the sampling apparatus while the soil vapor was collected.

2.4 Time of Year to Sample

2.4.1 Soil Vapor

Soil vapor samples are collected at any time during the year. Often, sampling is completed during the summer so the results can be used as a part of the CSM when selecting buildings to be sampled for indoor air during the heating season. However, like groundwater, samples need to be collected over time and differing conditions to make full assessment for demonstrations of compliance that would be necessary for closure of a site.

2.4.2 Sub-slab Vapor Samples

Sub-slab vapor samples should be collected from each quarter; however, the importance of sampling during the heating season must not be discounted, especially in Michigan. Soil vapor intrusion is more likely to occur when a building's heating system is in operation and doors and windows are closed. Soil vapor intrusion at a building may still be an issue outside of the heating season, where HVAC systems are actively managed to control the ratio of recirculated indoor air to make up air from outside the building. Information about the site and potentially affected structures, including the factors discussed in Section 1.3, should be considered in determining the timing of an investigation. Samples collected, including times when soil vapor intrusion is not expected to have its greatest effect on indoor air quality, may result in detections below any applicable screening levels. Single sampling events will not indicate that an exposure by vapor intrusion is or has not occurred.

2.5 Number of Sampling Rounds

Certain atmospheric and seasonal factors that are not within the evaluator’s control can affect soil gas values. Temperature, barometric pressure, and precipitation can affect soil gas values as these factors fluctuate over time. Since these factors will fluctuate, actions must be taken to ensure soil gas data collected at a site is representative of a variety of atmospheric conditions. Multiple sampling events over time account for this variation.

At a minimum, three soil vapor sampling events must occur at any given site, with no less than three months between events and one event during the summer. In cases where measured seasonal soil gas values vary significantly, additional sampling must be conducted. In most cases, the maximum number of sampling events will be four, with the events spaced evenly over a period of one year. Samples must be collected from the same location and depth during each sampling event.

Soil vapor samples may be collected from either permanent or temporary sampling points. Sampling may be easily duplicated if permanent sampling points are installed. However, if temporary points are used (e.g., those closed within 48 hours), actions must be taken to ensure

that subsequent samples are collected from the same location and depth as the initial samples. To do so, requires that the location and depth of temporary sampling points be accurately and durably recorded. Sampling points should be marked in the field to ensure that they can be subsequently found. The location of each sampling point must be recorded using GPS coordinates. The GPS surface coordinates should be accurate to less than ± 3 feet (e.g. submeter). In most cases this will preclude the use of a hand held GPS unit that is not capable of post processing the data. The methods used to record the temporary sampling locations and depths and a copy of the actual written record of such information must be included when reporting the data.

As stated above, investigating the soil vapor intrusion pathway involves more than one round of subsurface vapor, indoor air and/or outdoor air sampling. Additional rounds of data can be useful for reasons such as the following:

a. To characterize the nature and extent of subsurface vapor contamination (similar to the delineation of groundwater contamination), and to address corresponding exposure concerns.
b. To evaluate fluctuations in concentrations due to:
    - Different weather conditions (e.g., seasonal effects),
    - Changes in building conditions (e.g., various operating conditions of a building's HVAC system),
    - Changes in source strength,
    - Vapor migration or contaminant biodegradation processes (particularly when degradation products may be more toxic than the parent compounds), and
c. To confirm sampling results or the effectiveness of mitigation or remedial systems.

2.6 Sampling Locations

The general approach for selecting sampling locations as part of a soil vapor intrusion investigation is similar to the approach for the investigation of other environmental media (e.g., soil and groundwater). Sampling locations should be selected with consideration of the conceptual site model. These locations should be selected to meet the stated objectives of the sampling program. Additionally, similar to the investigation of soil and groundwater, it is typical to start at a known or suspected source and work outward. The specific approach, however, will be dependent upon site-specific and building-specific conditions.

2.6.1 Soil Vapor

If available, existing environmental data (e.g., groundwater and soil data) and site information, or the CSM, should be used to select locations for sampling soil vapor as part of a vapor intrusion investigation. Locations will vary depending upon surface features (e.g., presence or absence of buildings, areas of pavement, or vacant lot), and subsurface characteristics (e.g., soil stratigraphy, buried structures, utility corridors, or clay lenses), location of the vapor sources, as well as the specific purpose of the sampling. Therefore, a figure illustrating proposed sampling locations (with respect to both aerial position and depth), and actual

locations sampled in the field with relevant features should be included in all sampling work plans and reports.

Examples of how locations may vary given the specific purpose of the sampling follow. They include general guidelines that should be followed when selecting soil vapor sampling locations:

a) To evaluate the potential for current exposures, samples should be collected:
   - In the vicinity of a building's foundation, if sampling around a building with no surrounding surface confining layer, as well as between the building's foundation and the source (if known and not located beneath the building);
   - Along the site's perimeter; and
   - At a depth comparable to the depth of foundation footings (determined on a building-specific or site-specific basis), or at least one foot above the water table in areas where the groundwater table is less than six feet below grade.

b) To evaluate the potential for future exposures if development on a known or suspected contaminated area, representative samples should be collected:
   - In areas with either known or suspected subsurface sources of volatile chemicals, in areas where elevated readings were obtained with field equipment during previous environmental investigations, and in areas of varying concentrations of contamination in the upper groundwater;
   - In a grid pattern across the area (at an appropriate spacing interval for the size of the area), if information is limited for the area; and
   - At multiple depths from the suspected subsurface source, or former source, to a depth comparable to the expected depth of foundation footings.

c) To evaluate the potential for off-site soil vapor contamination, samples should be collected:
   - Along the site's perimeter;
   - In areas of potential subsurface sources of vapor contamination (e.g., a groundwater plume that has migrated off-site); and
   - At a depth comparable to the depth of foundation footings (determined on a site-specific basis), or at least one foot above the water table in areas where the groundwater table is less than six feet below grade.

d) To evaluate on-site and off-site preferential migration pathways in areas with low permeability soils, samples should be collected:
   - Along preferential soil vapor flow paths, such as sewer lines, utility corridors, trenches, pipelines, and other subsurface structures that are likely to be bedded with higher permeability materials; and
   - At depths corresponding to these subsurface features (determined by site-specific conditions).

e) To characterize on-site or off-site contamination in the vadose zone, samples should be collected:
   - In areas with either known or suspected sources of volatile chemicals, in areas where elevated readings were obtained with field equipment (e.g., PID), during previous soil, groundwater investigations, and in areas of varying concentrations of contamination in the upper groundwater regime; and
   - At appropriate depths associated with these areas (will depend on site-specific conditions).

f) To investigate the influence of contaminated groundwater or soil on soil vapor and to characterize the vertical profile of contamination, samples should be collected from clusters of soil vapor probes at varying depths in the vadose zone [Figure 2.2, Section 2.7.1] and preferably in conjunction with the collection of groundwater or soil samples.

If soil vapor samples are necessary to be collected at depths shallower than five feet, they may be prone to a negative bias due to infiltration of ambient air. Therefore, samples shallower than five feet should only be collected if site conditions, or the location of the vapor source, limit the appropriate sampling depth. Sampling procedures and results should be reviewed accordingly.

The depth of sampling near buildings with slab-on-grade foundations is dependent upon site-specific conditions (e.g., building surrounded by grassy or surface confining layer). When collecting soil vapor samples around a building with no surrounding surface confining layer (e.g., pavement or sidewalk), samples should be located in native or undisturbed soils away from fill material surrounding the building (approximately ten feet away from the building) to avoid sampling in an area that may be influenced by the building's operations. For example, operation of HVAC systems, fireplaces, or mechanical equipment (e.g., clothes dryers or exhaust fans/vents) in a building may exacerbate the infiltration of outdoor air into the vadose zone adjacent to the building. As a result, soil vapor samples collected in uncovered areas adjacent to the building may not be representative.

Investigations of soil vapor contamination should proceed outward from known or suspected subsurface sources, as appropriate, on an aerial basis until the nature and extent of subsurface vapor contamination has been characterized and human exposures have been addressed.

Other issues that need to be considered are included in the following subsections.

Lithology

Site soil or lithologic information should also be used to select appropriate locations and depths for soil gas probes. If on-site lithologic information is not available prior to conducting the soil gas investigation, at least one continuously cored boring to the proposed greatest depth of the soil gas investigation should be installed at the first sampling location. Depending on site conditions and the size of the investigation, additional continuously cored borings may be necessary. In determining appropriate sampling depths, strong consideration should be given to the lithology of the subsurface.

Sample Depth
Sample depths should be chosen to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface; and to ensure that representative samples are collected. Consideration should be given to the types of chemicals of concern, lithology encountered, and the depth of the vapor source. Sampling points should never be installed or collected within the zone of saturation.

The MDEQ recommends that soil gas probes be installed at a minimum of five feet bgs, if site conditions allow. Multi-depth sampling should be conducted at various locations throughout the site to assist in evaluating vapor migration. If no lithologic change or contamination is observed, default sampling depths may be selected for multi-depth sampling. For example, soil gas samples may be collected at five, 15, and 25 feet bgs, or at three discrete levels until either the groundwater is encountered or VOCs are not detected, whichever comes first. Under no circumstances may soil gas samples be collected from a depth of less than 18 inches.

Vertical profiles of soil gas concentration data are useful in evaluating the vapor intrusion pathway at many sites. However, vertical profiles may not be necessary at all sites and the data collection program should be guided by the conceptual site model and the sampling objectives. For example, at sites where the vapor source is shallow soil contamination, vertical profiling would not be an effective tool for the assessment (Berry-Spark. 2006).

2.6.2 Sub-slab Vapor

Existing environmental data (e.g., soil vapor, groundwater, and soil data), site information, CSM, and building construction details (e.g., basement, slab-on-grade, or multiple types of foundations, HVAC systems), should be considered when selecting buildings and locations within buildings for sub-slab vapor sampling.

At a minimum, these general guidelines should be followed when selecting buildings to sample for sub-slab vapors:

a) Buildings, including residential dwellings, located above or directly adjacent to known or suspected areas of subsurface volatile chemical contamination should be sampled;
b) Buildings in which screening with field equipment (e.g., PID, ppbRAE, Jerome Mercury Vapor Analyzer) suggests vapor mitigation is occurring; and
c) Buildings within known or suspected areas of subsurface volatile chemical contamination that are used or occupied by sensitive population groups (e.g., daycare facilities, schools, and nursing homes), should be given special consideration for sampling.

Investigations of sub-slab vapor and/or indoor air contamination should proceed outward from known or suspected sources, as appropriate, on an areal basis until the nature and extent of subsurface vapor contamination has been characterized and potential and current human exposures have been addressed. In cases of widespread vapor contamination and depending upon the basis for making decisions (e.g., a “blanket mitigation” approach within a specified area of documented vapor contamination), a statistically valid and representative number of

buildings from an identified study area, rather than each building, may be sampled. Prior to implementation, this type of sampling approach should be reviewed by the MDEQ.

Within a building, sub-slab vapor samples should be collected:

a) In at least one central location away from foundation footings (depending on area), and
b) From the soil or aggregate immediately below the basement slab or slab-on-grade.

The number of sub-slab vapor samples that should be collected in a building depends upon the overall aerial extent, the number of slabs (e.g., multiple slabs-on-grade in a large warehouse), and foundation types (e.g., combined basement and slab-on-grade in a residence). At least one sub-slab vapor sample should be collected to represent each area. Table 2.1 identifies the minimum number of sample locations that should be considered in evaluating sub-slab vapor.

Table 2.1 Number of Sub-slab Samples Required

Area of Floor (ft^2)	*Minimum Number of Samples*
< 1,000	4
1,000 < 1,500	5
1,500 < 2,500	6
2,500 to 12,500	1 sample for every 1,000 sq ft over 2,500
> 12,500	1 sample per additional 1,500 sq ft

2.6.3 Indoor Air

Existing environmental data (e.g., soil vapor, groundwater, and soil data), the CSM, and building construction details (e.g., basement, slab-on-grade, or multiple types of foundations; number and operation of HVAC systems; elevator shafts; tunnels or other confined-space entry points), should be considered when selecting buildings and locations within buildings for indoor air sampling. Indoor air samples are collected concurrently with sub-slab vapor and outdoor air samples.

Indoor air samples may play an important role in assessing the volatilization to indoor air pathway. In general indoor air samples may be utilized to:

a) Assess the need for immediate mitigation or response actions;
b) Evaluate the effectiveness of a mitigation system; or
c) Evaluate concentrations of contaminants in indoor air in limited circumstances where no other method exists to collect reliable and repeatable data in the soil gas, yet they are present and may present an indoor air inhalation risk.

Studies of indoor air samples have demonstrated that indoor concentrations are highly variable, and therefore demonstrating compliance with indoor air samples alone is not appropriate without sub-slab or soil gas samples. Indoor air samples collected at various sites across the nation have shown that even when properly collected, indoor air samples can fluctuate up to several times their documented concentration (Brenner, 2007). These fluctuations occur not only daily, but on smaller cycles. A seven year study of indoor air demonstrated there are also significant seasonal variations that have been observed in indoor air with VOCs being present approximately three times higher in the winter months than in summer (Rehwagen et al., 2003). Some of the fluctuations are known to be highly dependent on multiple variables, some of which are not yet completely understood (Oswald, 1988).

Indoor air samples are primarily utilized as a means to evaluate the need to immediately initiate mitigation. Indoor air samples may not be used as the primary or sole indication that vapor intrusion is not occurring into any structure. Identification of background concentrations will also not negate the need to mitigate exposures that are occurring as a result of the vaporization to indoor air pathway above the ASGSCs.

These general guidelines should be followed when selecting buildings to sample for indoor air:

a) Where sub-slab vapor samples were collected without indoor air samples, buildings in which elevated concentrations of contaminants were measured in sub-slab vapor samples to further assess the immediate need for mitigation;
b) Buildings in which screening with field equipment (e.g., PID, ppbRAE, Jerome Mercury Vapor Analyzer), suggests vapor intrusion is occurring such as when readings show increasing gradients, should be sampled to assess the need for immediate mitigation; and
c) Buildings within known or suspected areas of subsurface volatile chemical contamination that are used or occupied by sensitive population groups (e.g., daycare facilities, schools, and nursing homes), should be given special consideration for sampling.

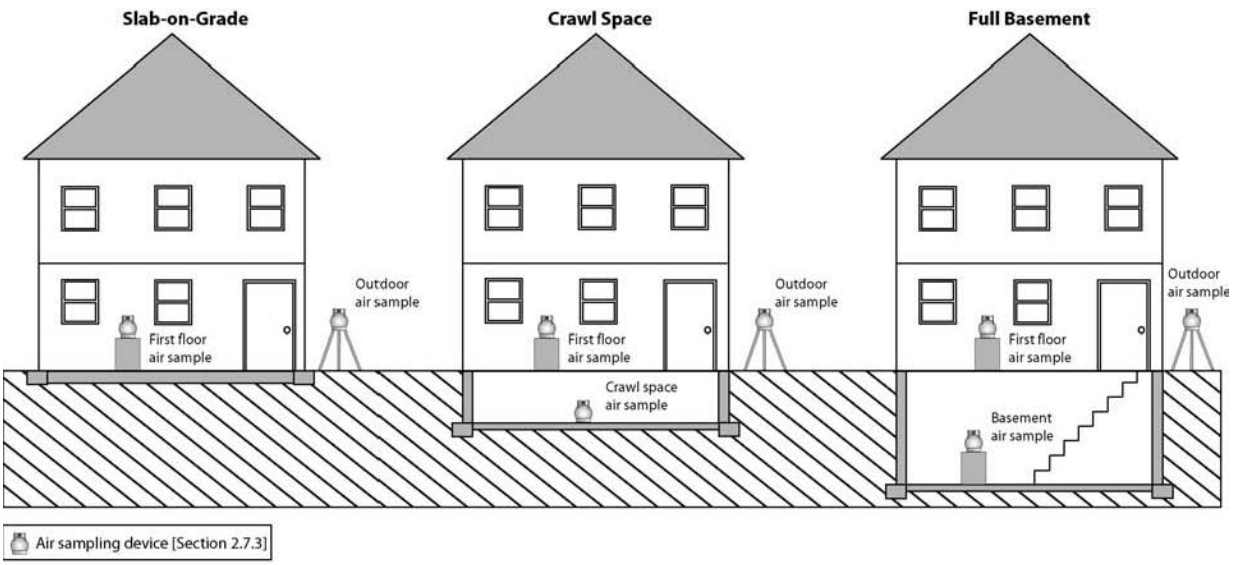
To characterize contaminant concentration trends and potential exposures, indoor air samples should be collected:

a) From the crawl space area;
b) From the basement (where vapor infiltration is suspected, such as near sump pumps, indoor wells, or in a central location), at a height approximately three feet above the floor to represent a height at which occupants normally are seated and/or sleep unless infants or small children are present, and then samples should be collected directly on the floor;
c) From the lowest level living space (in centrally located, high activity use areas) at a height approximately three feet above the floor to represent a height at which occupants normally are seated and/or sleep; and
d) If in a commercial setting (e.g., a strip mall), from multiple tenant spaces at a height approximately three feet above the floor to represent a height at which occupants normally are seated.

It should be noted that multiple sampling locations will be required in most circumstances.

These locations are illustrated in Figure 2.1.

Figure 2.1
Schematic of Indoor and Outdoor Air Sampling Locations:



From NYSDH, 2006

2.6.4 Outdoor Air

Typically, an outdoor air sample is collected outside of each building where an indoor air sample is collected. However, if several buildings are being sampled within a localized area, representative outdoor air samples may be appropriate. For example, one outdoor air sample may be sufficient for three houses being sampled in a cul-de-sac. Outdoor air samples should be collected from a representative upwind location, away from wind obstructions (e.g., trees or bushes), and at a height above the ground to represent breathing zones (three to five feet) [Figure 2.1]. A representative sample is one that is not biased toward obvious sources of volatile chemicals (e.g., automobiles, lawn mowers, oil storage tanks, gasoline stations, and industrial facilities). For buildings with HVAC systems that draw outdoor air into the building, an outdoor air sample collected near the outdoor air intake may be appropriate. An evaluation of an outdoor air source will not negate concentrations of soil vapor that have the potential to migrate to indoor air.

It will however, possibly identify other exposure routes that may be occurring and addressed if indoor air sampling is to be conducted in order to evaluate the immediate risk and need for mitigation. The ambient air sampling conducted as part of assessment of indoor air is not the sampling necessary to demonstrate compliance with R 299.5726(8). R 299.5726(8) requires a different sampling strategy including sampling height, sampling equipment, and overall number of sampling locations

2.7 Sampling Protocols and Considerations

The design and protocols of a soil gas survey program are dependent upon the objectives of the program, the types of contaminants anticipated to be present, and the facility conditions. Soil gas surveys are typically performed using active or passive methods.

The active method consists of the withdrawal of an aliquot of soil gas from the subsurface, typically with a sampling probe, followed by analysis of the withdrawn vapor. Analysis using the MDEQ approved analytical methods [Op Memo No. 2], may be performed on-site (if applicable) or, alternatively, soil gas samples can be stored in gas-tight containers and analyzed at an off-site laboratory. The active method is quantitative, and values are reported in concentration units (e.g., parts per million by volume, micrograms per meter cubed [$\mu g/m^3$], or micrograms per liter [μg/L-vapor]). This approach is the most common soil gas collection method for a number of reasons, including ease of sample collection, the opportunity for real-time data to direct further sampling, and the ability to acquire quantitative measurements.

The passive sampling method consists of the placement of an adsorbent into the subsurface and subsequent removal and analysis of the adsorbent. The adsorbent is typically placed in the upper end of an inverted container having an open bottom. Measured values cannot be reported as vapor concentrations, because the amount of vapor that comes into contact with the adsorbent is unknown; values can only be reported as total adsorbed mass (e.g., μg/L) or in some other form of relative units. Due to this limitation, passive surveys are useful for qualitative purposes only; however, they do provide very useful information. Since one effect of the adsorbent is to concentrate the soil gas, this method offers advantages over the active approach in locations of low vadose zone permeability and at facilities with lower contaminant concentrations (less than 0.1 μg/L-vapor). However, contaminants still must have an appreciable vapor pressure to be detected by this method.

Example Standard Operating Procedures for collecting an active soil gas, sub-slab sampling, and indoor air samples are included in Appendix C.

2.7.1 Soil Vapor

Soil gas sampling should not be conducted within 48 hours of a significant precipitation event (for example, 0.5 inch or greater of rain), or comparable on-site watering. However, whether sampling should be conducted is dependent on the depth to which soil is wetted relative to the planned depth of sample collection. The depth to which the soil is wetted is dependent, at least in part, on the ground cover, the type of soil, and the soil moisture content prior to the

precipitation event. Sampling should not occur if soils are wetted at a depth equal to or greater than the planned sampling depth.

Purge Volume

Prior to sampling, soil gas sampling probes should be purged to ensure that stagnant or ambient air is removed from the sampling system and to assure samples collected are representative of subsurface conditions. The purge volume or "dead space volume" can be calculated by summing the volume of the probe screened interval (including filter pack void space accounting for porosity of sand pack), the volume of tubing from the probe tip to the ground surface, and the volume of above ground tubing connecting the soil probe to the sample collection device.

The monitoring point should be purged until at least three volumes of the full sampling system have been evacuated. Purging should be conducted at flow rates and vacuum conditions similar to those for sample collection (Section 2.7.1, Flow Rates). If the soil matrix is such that recommended purging is not possible due to low or no flow soil gas conditions (i.e., gas will not flow or flow is severely restricted), the probe should be advanced deeper to look for zones of higher permeability. If the deeper probe does not encounter a higher permeability zone and low or no flow conditions persist, the probe should be abandoned and a new probe advanced elsewhere on the site.

If low or no flow soil gas conditions are found across the site and soil gas sampling is therefore not possible, the evaluator may propose an alternative method of soil gas sampling, such as sub-slab sampling. Since sub-slab gas samples are generally extracted from the porous granular material underlying a slab, sub-slab sampling may be a practical method of soil gas sampling when subsurface sampling is not.

Flow Rates

The purging or sampling flow rate should be attainable in the lithology adjacent to the soil gas probe. The MDEQ recommends purging or sampling at rates between 100 to 200 ml/min to limit stripping, prevent ambient air from diluting the soil gas samples, and to reduce the variability of purging rates. The low flow purge rate increases the likelihood that representative samples may be collected. A regulated flow meter should be placed between the probe and the sample container to control and measure the flow rate. The sampling rate should be reduced and may be modified based on specific field conditions, including the vacuum observed. The purge/sample rate may be modified based on conditions encountered in individual soil gas probes. These modified rates should be documented in the soil gas report.

To measure sample collection vacuum, a vacuum gauge must be placed between the probe and the sample container. It is recommended that a sampling vacuum of less than 100 inches of water be obtained. When a vacuum pump is used, samples should be collected on the intake side of the vacuum pump to prevent potential contamination from the pump. Vacuum readings or qualitative evidence of a vacuum should be recorded on field data sheets for each sample.

To achieve the target sampling vacuum, the sampling flow rate should be adjusted using the flow regulator. If the sampling vacuum exceeds 100 inches of water, and a reduction in the sampling flow rate does not reduce the vacuum, continue to attempt to collect the sample, recording flow rate and vacuum conditions. Data for samples collected under a vacuum greater than 100 inches of water must be flagged no-flow or low-flow. Conditions can be evaluated in each soil gas probe with gas tight syringes to qualitatively determine if a high vacuum soil condition (e.g., suction is felt while the plunger is being withdrawn) is present.

Sampling Tube

Sampling tubes should be of a small diameter (1/8 to 1/4 inch) and made of material (e.g., nylon, polyethylene, copper, or stainless steel) which will not react or interact with site contaminants. For example, metal tubes should not be used for collection of hydrogen sulfide samples. Clean, dry tubing should be utilized at all times. If moisture, water, or an unknown material is present in the probe prior to insertion, the tubing should be decontaminated or replaced. After use at each location non-reusable (e.g., nylon or polyethylene), sampling tubes should be discarded; or reusable sampling tubes should be properly decontaminated.

Soil Gas Probe Installation Methods

Permanent probes, wells, or other soil gas sampling devices are recommended to allow for the assessment of seasonal variability. However, temporary sampling points, such as through the probe rods of a direct push drill machine, may be utilized as part of the site investigative process

Permanent, semi-permanent, or temporary soil gas sampling points may be installed, using a variety of drilling methods including hand augers, hydraulically driven probes, and various drilling rigs. The sampling points discussed here are discrete sampling points that are installed and then left to equilibrate. The equipment used for sampling does not remain over the boring while the sample is being collected. The mud rotary drilling method is not an acceptable method to install soil gas probes. Other drilling methods such as air rotary and rotosonic can adversely affect soil gas data during and after drilling and will require extensive equilibration times. Therefore, they are not recommended.

Other soil gas probe designs and construction (e.g., soil gas wells or nested wells), may be appropriate and may be installed in a single boring when proper installation techniques are utilized. When additional sampling is not anticipated, such probes may be properly removed or decommissioned after completion of the soil gas investigation. Unless soil gas probes are properly abandoned the same day they are installed, probes must be properly secured, capped, and completed to prevent infiltration of water or ambient air into the subsurface and to prevent accidental damage or vandalism. For completion of the probe at the surface, the following components may be installed, as necessary:

1) Gas-tight valve or fitting for capping the vapor point,
2) Fitting for connection to above ground sampling equipment,
3) Protective flush mounted or above ground well vaults, or
4) Guard posts.

An example of the MDEQ's Standard Operating Procedures is provided in Appendix C; however, the following procedures must be considered:

1) The probe tip should be installed midway within a minimum of one foot of sand pack. The sand pack should be appropriately sized (e.g., no smaller than the adjacent formation), and installed to minimize disruption of airflow to the sampling tip.

2) At least one foot of dry granular bentonite should be placed on top of each sand pack to preclude the infiltration of hydrated bentonite grout. The borehole should be grouted to the surface with hydrated bentonite. With respect to deep probe construction with multiple probe depths, the borehole should be grouted between probes. One foot of dry granular bentonite should be emplaced between the filter pack and the grout at each probe location.

3) The use of a down hole probe support may be required for deep probe construction. Such probe supports may be constructed from a one-inch diameter bentonite/cement grouted PVC pipe or other solid rod, or equivalent, allowing probes to be positioned at discrete intervals. The support rod must be solid (internally or externally) to avoid possible cross-contamination or ambient air intrusion.

4) Tubing should be properly marked at the surface to identify the probe location and depth.

5) As-built diagrams for probes or wells should be completed as part of the sampling documentation.

6) To allow for subsurface conditions to equilibrate, the following equilibration times are recommended:
   a) For probes installed with the direct push method where the drive rod does not remain in the ground, leak tests and soil gas sampling should not be conducted for at least 30 minutes following probe installation.
   b) For probes installed with hollow stem auger or other alternate drilling methods, leak tests and soil gas sampling should not be conducted for at least 48 hours (depending on site lithologic or drilling conditions), after the soil gas probe installation.
   c) The probe installation and sampling times must be recorded as part of the sampling documentation.

Vapor Sampling with a Hydraulic Driven Probe

In general, a hydraulic probe drives a rod to a predetermined depth, and a screen is exposed which contains the inlets of the soil gas probe. After a sample is collected, both the drive rod and tubing are removed. Though these points do offer an initial sampling point, because a point is not installed, duplicate or repeated sampling is not possible unless the probe replicates the

exact initial survey. There are multiple types and manufactures of these types of sampling devices; however, in general the MDEQ makes the following recommendations in order to collect a proper sample.

1) Hydrated bentonite should be used to seal around the drive rod for each sampling depth at the ground surface to prevent ambient air intrusion from occurring.
2) The inner soil gas pathway from probe tip to the surface should be continuously sealed (e.g., a sampling tube attached to a screw adapter fitted with an o-ring and connected to the probe tip) to prevent infiltration.
3) To allow for disturbed subsurface conditions to equilibrate, soil gas sampling from each sampling point should not be conducted for at least 20 minutes following the probe reaching the sampling depth.

Decontamination
After each use, drive rods and other reusable components should be properly decontaminated to prevent cross contamination. Decontamination methods include:

- Three-stage wash and rinse (e.g., wash equipment with a nonphosphate detergent, rinse with tap water, and finally rinse with distilled water); and/or
- Steam cleaning process.

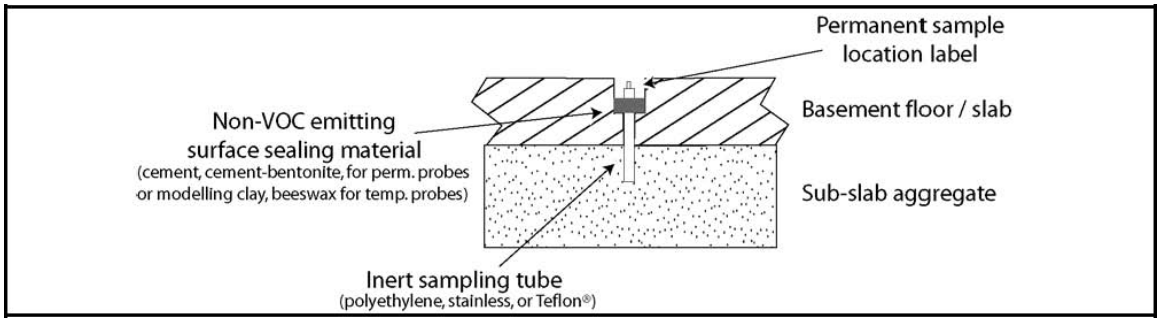
Sample Log
A sample log sheet must be maintained that summarizes all of the following information:

a) Sample identification,
b) Date and time of sample collection,
c) Sampling depth,
d) Identity of samplers,
e) Sampling methods and devices,
f) Soil vapor purge volumes,
g) Volume of soil vapor extracted,
h) If canisters used, vacuum of canisters before and after samples collected,
i) Apparent moisture content (dry, moist, saturated) of the sampling zone, and
j) Chain of custody protocols and records used to track samples from sampling point to analysis.

2.7.2 Sub-slab Vapor

During colder months, heating systems should be operating to maintain normal indoor air temperatures (i.e., 65 to 75°F) for at least 24 hours prior to and during the scheduled sampling time. Prior to installation of the sub-slab vapor probe, the building floor should be inspected, and any penetrations (cracks, floor drains, utility perforations, sumps) should be noted and recorded. Probes should be installed at locations where the potential for ambient air infiltration via floor penetrations is minimal. Many of the considerations in 2.7.1 for soil gas sampling also apply (flow rates, leak test, purge rates), when sampling points beneath a slab.

Figure 2.3
Schematic of a generic sub-slab vapor probe: [Note: Many variations exist and may be proposed in a work plan. Proposed installations should meet the sampling objectives and requirements of the analytical methods.]



Sub-slab vapor probe installations [Figure 2.3] may be permanent, semi-permanent, or temporary. A vacuum should not be used to remove drilling debris from the sampling port. Sub-slab implants or probes should be constructed in the same manner at all sampling locations to minimize possible discrepancies. The following should be addressed in any sub-slab probe construction:

a) Permanent recessed probes should be constructed with brass or stainless steel tubing and fittings.
b) Temporary probes should be constructed with inert tubing (e.g., polyethylene, stainless steel, nylon, Teflon®), of the appropriate size (typically 1/8 inch to 1/4 inch diameter), and of laboratory or food grade quality.
c) Tubing should not extend further than two inches into the sub-slab material.
d) Porous, inert backfill material (e.g., glass beads, washed #1 crushed stone), should be added to cover about one inch of the probe tip for permanent installations.
e) The implant should be sealed to the surface with non-VOC-containing and non-shrinking products for temporary installations (e.g., grout, melted beeswax, putty) or cement for permanent installations.

To obtain representative samples that meet the data quality objectives, sub-slab vapor samples should be collected in the following manner:

a) After installation of the probes, one to three volumes (i.e., the volume of the sample probe and tube), must be purged prior to collecting the samples to ensure samples collected are representative.
b) Flow rates for both purging and collecting must not exceed 200 ml/min to minimize ambient air infiltration during sampling.

c) Samples should be collected using conventional sampling methods in an appropriate container, one which:
   - Meets the objectives of the sampling (e.g., investigation of areas where low or high concentrations of volatile chemicals are expected; to minimize losses of volatile chemicals that are susceptible to photodegradation).
   - Is consistent with the sampling and analytical methods (e.g., low flow rate; canisters if analyzing by using U.S. EPA Method TO-15).
   - Is certified clean by the laboratory.
d) Sample size depends upon the volume of that which will achieve minimum reporting limits, the flow rate, and the sampling duration; and ideally, samples should be collected over the same period of time as concurrent indoor and outdoor air samples.
e) Any pertinent observations, such as spills, floor stains, smoke tube results, odors, and readings from field instrumentation (e.g., vapors via PID, ppbRAE, Jerome Mercury Vapor Analyzer), should be recorded.

Additional documentation that could be gathered to assist in the interpretation of the results includes information about air flow patterns and pressure relationships obtained by using smoke tubes or other devices (especially between floor levels and between suspected contaminant sources and other areas), the barometric pressure, and photographs to accompany floor plan sketches.

2.7.3 Indoor Air

During colder months, heating systems should be operating to maintain normal indoor air temperatures (i.e., 65 to 75°F), for at least 24 hours prior to and during the scheduled sampling time. Prior to collecting indoor samples, a pre-sampling inspection should be performed to evaluate the physical layout and conditions of the building being investigated, to identify conditions that may affect or interfere with the proposed sampling, and to prepare the building for sampling. This process is described in Section 2.10.

In general, indoor air samples should be collected in the following manner:

a) Sampling duration should reflect the exposure scenario being evaluated without compromising the detection limit or sample collection flow rate (e.g., an eight hour sample from a workplace with a single shift versus a 24-hour sample). To ensure that air is representative of the locations sampled and to avoid undue influence from sampling personnel, samples should be collected for at least one hour. If the goal of the sampling is to represent average concentrations over longer periods, then longer duration sampling periods may be appropriate. Typically, 24-hour samples are collected from residential settings.
b) Personnel should avoid lingering in the immediate area of the sampling device while samples are being collected.
c) Sample flow rates must conform to the specifications in the sample collection method and, if possible, should be consistent with the flow rates for concurrent outdoor air and sub-slab samples.

d) Samples must be collected, using conventional sampling methods, in an appropriate container, one which:
   - Meets the objectives of the sampling (e.g., investigation of areas where low or high concentrations of volatile chemicals are expected; to minimize losses of volatile chemicals that are susceptible to photodegradation).
   - Is consistent with the sampling and analytical methods (e.g., low flow rate; Summa® canisters if analyzing by using U.S. EPA Method TO-15).
   - Is certified clean by the laboratory.

The following actions should be taken to document conditions during indoor air sampling and ultimately to aid in the interpretation of the sampling results [Section 3]:

a) Historic and current uses and storage of volatile chemicals should be identified, especially if sampling within a commercial or industrial building (e.g., use of volatile chemicals in commercial or industrial processes and/or during building maintenance).
b) A product inventory survey documenting sources of volatile chemicals present in the building during the indoor air sampling that could potentially influence the sample results should be completed [Section 2.10].
c) The use of heating or air conditioning systems during sampling should be noted.
d) Floor plan sketches should be drawn that include the floor layout with sampling locations, chemical storage areas, garages, doorways, stairways, location of basement sumps, or subsurface drains, and utility perforations through building foundations, HVAC system supply and return registers, footings that create separate foundation sections, and any other pertinent information should be completed.
e) Outdoor plot sketches should be drawn that include the building site, area streets, outdoor air sampling locations (if applicable), and paved areas.
f) Weather conditions (e.g., precipitation, indoor and outdoor temperature) and ventilation conditions (e.g., heating system active and windows closed) should be reported.
g) Any pertinent observations, such as spills, floor stains, smoke tube results, odors, and readings from field instrumentation (e.g., vapors via PID, ppbRAE, Jerome Mercury Vapor Analyzer) should be recorded.

Additional documentation that could be gathered to assist in the interpretation of the results includes information about air flow patterns and pressure relationships obtained by using smoke tubes or other devices (especially between floor levels, between suspected contaminant sources and other areas), the barometric pressure, and photographs to accompany floor plan sketches.

A sample log sheet summarizing all of the following should be maintained:

a) Ample identification,
b) Date and time of sample collection,
c) Sampling height,
d) Identity of samplers, and
e) Sampling methods and devices.

f) Depending upon the method, volume of air sampled.
g) If canisters are used, vacuum of canisters before and after samples collected.
h) Chain of custody protocols and records used to track samples from sampling point to analysis.

2.7.4 Outdoor Air

Outdoor air samples should be collected simultaneously with indoor air samples to evaluate the potential influence, if any, of outdoor air on indoor air quality. They may also be collected simultaneously with soil vapor samples to identify potential outdoor air interferences associated with infiltration of outdoor air into the sampling apparatus while the soil vapor was collected. To obtain representative samples that meet the data quality objectives, outdoor air samples should be collected in a manner consistent with that for indoor air samples (described in Section 2.7.3).

The following actions should be taken to document conditions during outdoor air sampling and ultimately to aid in data evaluation [Section 3]:

a) Outdoor plot sketches should be drawn that include the building site, area streets, outdoor air sampling locations, the location of potential interferences (e.g., gasoline stations, factories, lawn movers), and paved areas;
b) Weather conditions (e.g., precipitation, outdoor temperature, should be reported; and
c) Any pertinent observations, such as odors, readings from field instrumentation, and significant activities in the vicinity (e.g., operation of heavy equipment or dry cleaners) should be recorded.

2.7.5 Tracer Gas

Leakage during soil gas sampling may dilute samples with ambient air and produce results that underestimate actual site concentrations or contaminate the sample with external contaminants. Tracer gases serve as a QA/QC measure to verify the integrity of the soil vapor probe seal. Without the use of a tracer, there is no way to verify that a soil vapor sample has not been diluted by other air sources at the surface. Leak tests with a tracer gas should be conducted to determine whether leakage is present (e.g., the leak check compound is detected and confirmed in the test sample after its application). Leak tests should be conducted at every soil gas probe.

Depending on the nature of the contaminants of concern, a number of different compounds can be used as a tracer. Typically, sulfur hexafluoride or helium are used as tracers because they are readily available, have low toxicity, and can be monitored with portable measurement devices. Butane and propane (or other gases) could also be used as a tracer in some situations. Compounds other than those mentioned here may be appropriate, provided they meet project-specific data quality objectives. Where applicable, steps should be taken to ensure that the gas used by the laboratory to clean the air sampling container is different from the gas used as a tracer during sampling (e.g., helium).

The protocol for using a tracer gas is straightforward. Simply enrich the atmosphere in the immediate vicinity of the area where the probe intersects the ground surface with the tracer gas, and measure a vapor sample from the probe for the presence of high concentrations (> 10%) of the tracer. A cardboard box, a plastic pail, or even a garbage bag can serve to keep the tracer gas in contact with the probe during the testing. If there are concerns about infiltration of ambient air through other parts of the sampling train (such as around the fittings, not just at the probe/ground interface), then consideration should be given to ensuring that the tracer gas is in contact with the entire sampling apparatus. In these cases, sampling personnel may prefer to use a liquid tracer, i.e., soaking paper towels with a liquid tracer and placing the towels around the probe/ground interface, around fittings, and/or in the corner of a shroud.

There are two basic approaches to testing for the tracer gas:

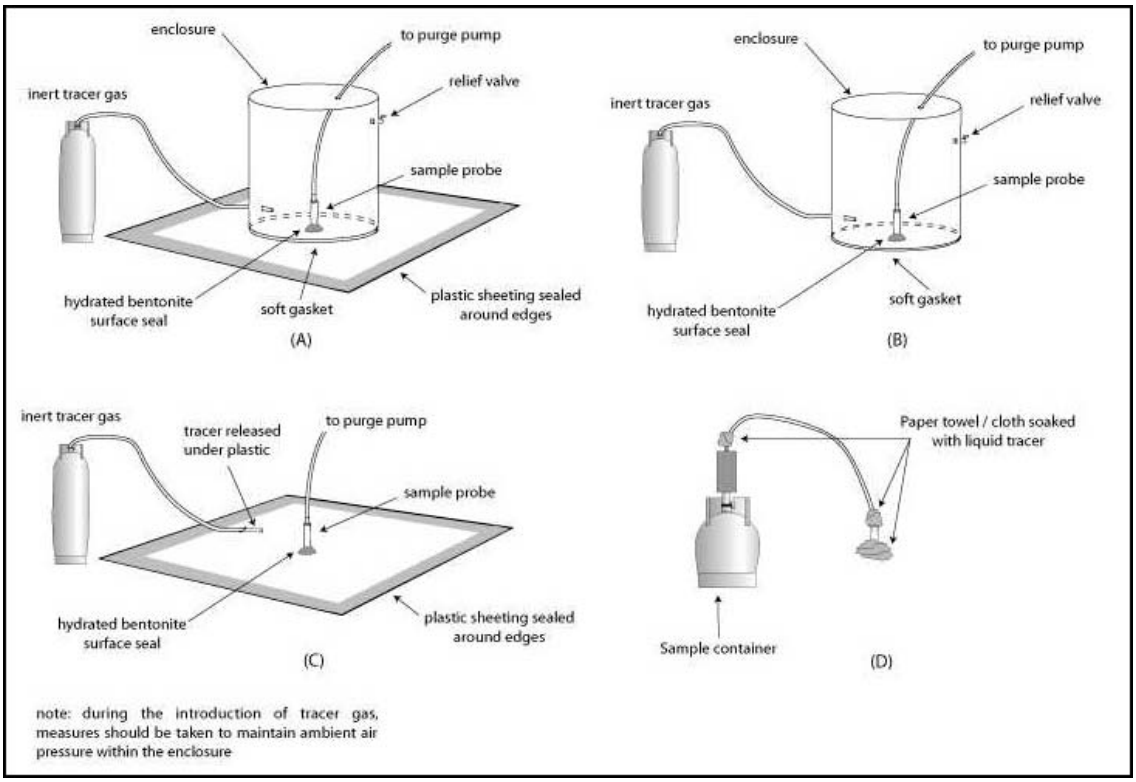
1) Include the tracer gas in the list of target compounds reported by the laboratory; or
2) Use a portable monitoring device to analyze a sample of soil vapor for the tracer prior to and after sampling for the compounds of concern. (Note: The tracer gas samples can be collected via syringe and Tedlar® bag. They need not be collected in canisters or minicans.)

The advantage of the second approach is that the real time tracer sampling results can be used to confirm the integrity of the probe seals prior to formal sample collection; however, some tracer gases may not be detected in the field, but still result in a raised detection limit which may limit the usefulness of the data.

Figure 2.4 depicts common methods for using tracer gas. In examples a, b, and c, the tracer gas is released in the enclosure prior to initially purging the sample point. Care should be taken to avoid excessive purging prior to sample collection. Care should also be taken to prevent pressure build-up in the enclosure during introduction of the tracer gas. Inspection of the installed sample probe, specifically noting the integrity of the surface seal and the porosity of the soil in which the probe is installed, will help to determine the tracer gas setup. Figure 2.4a may be most effective at preventing tracer gas infiltration; however, it may not be appropriate depending on site-specific conditions. Figures 2.4b and 2.4c may be sufficient for probes installed in tight soils with well constructed surface seals. Figure 2d provides an example of using a liquid tracer. In all cases, the same tracer gas application should be used for all probes at any given site.

Figure 2.4

Schematics of generic tracer gas applications when collecting soil vapor samples. Since minor leakage around the probe seal should not materially affect the usability of the soil vapor sampling results, the mere presence of the tracer gas in the sample should not be a cause for alarm. Consequently, portable field monitoring devices with detection limits in the low ppm range are more than adequate for screening samples for the tracer. If tracer gas is observed in a sample, the probe seal should be enhanced to reduce the infiltration of outdoor air. (NYSDH, 2006)



Where permanent or semi-permanent sampling probes are used, tracer gas samples should be collected at each of the sampling probes during the initial stages of a soil vapor sampling program. If the results of the initial samples indicate that the probe seals are adequate, reducing the number of locations at which tracer gas samples are employed may be considered. At a minimum, tracer gas samples should be collected with at least 10% of the soil vapor samples collected in subsequent sampling rounds. When using permanent soil vapor probes as part of a long-term monitoring program, annual testing of the probe integrity is recommended. Where temporary probes are used, tracer gas should be used at every sampling location, every time.

2.7.6 Future Structures

To assess vapor intrusion threats to future structures in areas that acceptable soil gas readings can be obtained, sampling points must be installed in the area having the highest contaminant concentrations on the site. In addition, these areas will need to have samples collected at multiple depths. Generally, four sampling locations should be utilized to evaluate future structures. However, if the size of the source area exceeds 2,500 square feet, more than four sampling points will be required, with the total number dependent on the overall size of the plume. In general, sampling points should be spaced no greater than 50 feet apart and preferentially placed within the anticipated footprint of the future structure, if known.

The evaluation must include a point-by-point comparison to evaluate building conditions for future site structure and what restrictions may be necessary to address the indoor air pathway.

2.8 Quality Assurance and Quality Control

In general, appropriate QA/QC procedures should be followed during all aspects of sample collection and analysis to ensure that sampling error is minimized and high quality data are obtained. Sampling personnel should avoid actions (e.g., fueling vehicles, using permanent marking pens, wearing freshly dry-cleaned clothing, or personal fragrances) which can cause sample interference in the field. Portable air monitoring equipment or field instrumentation should be properly maintained, calibrated, and tested to ensure validity of measurements.

Air sampling equipment should be stored, transported, and between samples, decontaminated in a manner consistent with the best environmental consulting practices to minimize problems such as field contamination and cross-contamination. Samples should be collected using certified clean sample devices. Where applicable, steps should be taken to ensure that the gas used by the laboratory to clean the sample device is different from the gas used as a tracer during sampling (e.g., helium). Samples should meet sample holding times and temperatures and should be delivered to the analytical laboratory as soon as possible after collection. In addition, laboratory accession procedures should be followed, including field documentation (sample collection information and locations), chain of custody, field blanks, field sample duplicates, and laboratory duplicates, as appropriate.

Some methods call for collecting samples in duplicate to assess errors. Duplicate and/or split samples should be collected in accordance with the sampling and analytical methods being implemented.

When reporting sampling data, the tables should reflect and clearly identify the laboratory, method, sample date, container, sorbent (if applicable), analytical date, and reporting limit. More information can be found in Op Memo No. 2.

2.9 Analytical Methods

Typically, a minimum reporting limit of one microgram per cubic meter (1 $\mu g/m^3$) or less is sufficient for most compounds. However, there are several compounds that detection levels of less than 1 $\mu g/m^3$ are required [Op Memo 2]. Commonly used analytical methods, include the following:

a) The U.S. EPA Method TO-15 for a wide range of VOCs (e.g., samples from evacuated canisters).
b) The U.S. EPA Method TO-17 for VOCs (e.g., samples collected with sorbent tubes).
c) The U.S. EPA Method TO-15 for VOCs with selective ion monitoring (e.g., to achieve minimum reporting limits lower than those achieved with Method TO-15 alone).

TO-15 is the preferred method for initial site characterization or when a wide range of volatiles are present. TO-17 does offer a different range of analytical compounds that can be detected; however, as stated, the methodology is dependent upon several factors including the use of the proper adsorbents that are present at a facility. In some cases, and for some contaminants, this will result in multiple samples being collected in order to complete the collection of one sample location. Therefore, when utilizing TO-17, additional samples should be collected for verification by TO-15.

With both methods, the laboratory should verify that it is capable of detecting the appropriate compounds and can report them at the appropriate reporting limit. In addition, verification that the tracer gas can be detected, if present, and that if it is present it will not significantly raise the detection level if only trace amounts are present.

More information can be found in Op Memo No. 2.

2.9.1 Compounds Not Detected by TO-15 or TO-17

If VOCs are present, the vapor intrusion pathway is always relevant [Section 1.1]. Though TO-15 and TO-17 are routinely able to detect most VOCs, several volatiles may be present in the soil and groundwater that cannot be detected. Many of these compounds can only be detected using TO methods in ambient air samples that are inappropriate for the collection of vapor samples in the soil, due to extremely high flow rates or sampling methodology. At sites where these compounds are present, indoor air samples may need to be utilized to fully evaluate the associated risk. In most cases, these compounds are not likely to have any interference associated with background concentrations. However, sub-slab, as well as indoor air samples, should also be simultaneously collected for those compounds that can be detected by TO-15 or TO-17 to provide additional indication of other potential “marker” chemicals that can be used to aid in establishing a line of evidence.

2.9.2 Use of 8260B to Analyze Vapors

Laboratory Method 8260B (commonly used for the analysis of groundwater) does not have a precisely defined procedure for vapor phase sample introduction with purge and trap analytical equipment, therefore the procedures must be significantly modified to accommodate vapor phase samples. General trends have shown TO-15 results higher than 8260B (Hayes, 2008). It has also been reported there is no standard or unified approach for the methods modification (Tuday, 2008), and the accuracy of soil vapor results are often not measured by any of the standard 8260B quality control samples. Using 8260B's "liquid phase" calibration always requires an assumption that may provide for inadequate interpretations (Hayes, 2008). In a survey conducted by Columbia Analytical Services Inc., it found in general, that many of the 8260B procedures, when modified, did not include any quality control check to specifically measure potential losses of vapor phase samples at the point of introduction in the analytical system. It was also noted in that study that the QA/QC checks that were being performed (e.g. MS/MSD) were not relevant to the actual sample vapor matrix (Tuday, 2008).

Therefore, the use of 8260B is not appropriate to demonstrate compliance with criteria. It may be utilized as a site screening tool to evaluate areas of the site where concentrations are higher, but all samples that were analyzed and detected below the ASGSCs should be reevaluated utilizing one of the established methods identified in Section 2.9.1 and Op Memo No. 2.

2.9.3 Soil Gas Sample Containers

For samples analyzed off-site (at a fixed laboratory) sampling containers approved for use with the appropriate method must be utilized. The MDEQ strongly recommends working with the laboratory that will analyze the samples in choosing appropriate sample containers. Smaller sized containers for TO-15, or one liter, or 500 ml, are recommended. The analytical laboratory or other supplier of sample containers must certify that all sample containers supplied by them are free of contaminants at concentrations exceeding contaminant detection levels. Samples may be collected in Tedlar bags or gas-tight syringes, only if samples are analyzed on-site in a mobile laboratory and on the same day of the collection; however, in most cases the samples should be utilized for field screening purposes only (See Section 2.9.5).

2.9.4 Target Compounds

Soil vapor and sub-slab vapor samples should be analyzed for a wide range of volatile chemicals during the first round of sampling (at a minimum), unless it can be demonstrated that an abbreviated or site-specific compound list is appropriate. This is analogous to analyzing groundwater samples for a suite of compounds (e.g., U.S. EPA's target compound list/target compound list chemicals) during the initial rounds of site characterization. Based on the initial sampling results, development and application of a site-specific compound list may be considered for analysis of subsequent soil vapor and sub-slab vapor samples.

If a site-specific compound list is developed, it should include the following:

a) Volatile chemicals which have been previously detected in environmental media (e.g., soil, groundwater, and air) at the site,
b) Volatile chemicals which are known or demonstrated constituents of the contamination in question (e.g., petroleum products or tars from former manufactured gas plants), and
c) Expected degradation products of the chemicals identified in a or b.

2.9.5 Indoor Air

Indoor and outdoor air samples should be analyzed for a wide range of volatile chemicals if there is no existing data for subsurface vapors, unless it can be demonstrated that an abbreviated or site-specific compound list is appropriate. If indoor air sampling is appropriate based on the levels of volatile chemicals in subsurface vapors, analysis of indoor air samples specifically for those volatile chemicals may be considered.

2.9.6 Outdoor Air

Outdoor air samples should be analyzed in a manner consistent with corresponding indoor air samples.

2.9.7 Field Laboratories and Mobile Gas Chromatographs

Use of field laboratories and mobile GCs may be a valuable tool when collecting soil vapor samples and should be considered on a site-specific basis. However, screening tools such as these are not acceptable when collecting sub-slab vapor, indoor air samples, and outdoor air samples for the purpose of demonstrating compliance with criteria. Only U.S. EPA approved procedures and those identified in Op Memo No. 2 should be utilized. Some mobile laboratories are capable of analyzing by the recommended methods. Questions regarding a mobile laboratory's certification should be directed to the laboratory itself.

Field laboratories are a cost effective way to establish through limited mobilizations the aerial extent of impacted soil gas, soil, and groundwater. As stated in 2.9.2 the use of 8260B cannot be utilized to demonstrate compliance with any site specific criteria; if used as a field screening tool, the results should be confirmed by collecting duplicates from selected locations for fixed laboratory analysis by an approved method, in order to verify the field screening results. Strong consideration and bias towards verifying the results of sampling locations that identify the extent of the vapors should be considered, as compared to verifying level of exceedances at a particular facility. Field laboratories and GCs should validate the vapor introduction system using NIST-traceable vapor phase standard to obtain the best accuracy possible.

2.10 Surveys and Pre-sampling Building Preparation for Indoor Air Sampling

2.10.1 Pre-Sampling Building Inspection and Preparation

A pre-sampling inspection should be performed prior to each sampling event to identify and minimize conditions that may interfere with the proposed testing. The inspection should evaluate the type of structure, floor layout, air flows and physical conditions of the building(s) being studied. This information, along with information on sources of potential indoor air contamination (Section 2.10.2), should be identified on a building inventory form. An example of a building inventory form is given in the SOP for sampling indoor air in Appendix C. Items to be included in the building inventory include the following:

a) Construction characteristics, including foundation cracks and utility penetrations or other openings that may serve as preferential pathways for vapor intrusion;
b) Presence of an attached garage;
c) Recent renovations or maintenance to the building (e.g., fresh paint, new carpet, or furniture);
d) Mechanical equipment that can affect pressure gradients (e.g., heating systems, clothes dryers, or exhaust fans);
e) Use or storage of petroleum products (e.g., fuel containers, gasoline operated equipment, and unvented kerosene heaters); and
f) Recent use of petroleum-based finishes or products containing volatile chemicals.

Each room on the floor of the building being tested and on lower floors, if possible, should be inspected. This is important because even products stored in another area of a building can affect the air of the room being tested.

Potential interference from products or activities releasing volatile chemicals should be controlled to the extent practicable. Removing the source from the indoor environment prior to testing is the most effective means of reducing interference. Ensuring that containers are tightly sealed may be sufficient. When testing for volatile organic compounds, containers should be tested with portable vapor monitoring equipment to determine whether compounds are leaking. The inability to eliminate potential interference may be justification for not testing, especially when testing for similar compounds at low detection levels. The investigator should consider the possibility that chemicals may adsorb onto porous materials and may take time to dissipate.

In some cases, the goal of the testing is to evaluate the impact from products used or stored in the building (e.g., pesticide misapplications, school renovation projects). If the goal of the testing is to determine whether products are an indoor volatile chemical contaminant source, removal of these sources is not appropriate.

Once interfering conditions are corrected, (if applicable) ventilation may be appropriate prior to sampling in order to minimize residual contamination in the indoor air. If ventilation is appropriate, it should be completed 24 hours or more prior to the scheduled sampling time. Where applicable, ventilation can be accomplished by operating the building's HVAC system to maximize outside air intake. Opening windows, doors, and operating exhaust fans may also help or may be appropriate if the building has no HVAC system.

Air samples are sometimes designed to represent typical exposure in a mechanically ventilated building, and the operation of HVAC systems during sampling should be noted on the building inventory form [Appendix C]. When samples are collected, the building's HVAC system should be operating in a manner consistent with normal operating conditions when the building is occupied (e.g., schools, businesses). Unnecessary building ventilation should be avoided within 24 hours prior to and during sampling. During colder months, heating systems should be operating to maintain normal indoor air temperatures (i.e., 65 to 75°F) for at least 24 hours prior to and during the scheduled sampling time.

Depending upon the goal of the indoor air sampling, some situations may warrant deviation from the above protocol regarding building ventilation. In such cases, building conditions and sampling efforts should be understood and noted within the framework and scope of the investigation.

To avoid potential interferences and dilution effects, occupants should make a reasonable effort to avoid all of the following for 24 hours prior to sampling:

a) Opening any windows, fireplace dampers, openings or vents;
b) Operating ventilation fans unless special arrangements are made;
c) Smoking in the building;
d) Painting;
e) Using a wood stove, fireplace, or other auxiliary heating equipment (e.g., kerosene heater);
f) Operating or storing an automobile(s) in an attached garage;
g) Allowing containers of gasoline or oil to remain within the house or garage area, except for fuel oil tanks;
h) Cleaning, waxing or polishing furniture, floors or other woodwork with petroleum or oil based products;
i) Using air fresheners, scented candles, or odor eliminators;
j) Engaging in any hobbies that use materials containing volatile chemicals;
k) Using cosmetics including hairspray, nail polish, nail polish removers, perfume/cologne;
l) Lawn mowing or snow blowing;
m) Applying pesticides;
n) Using building repair or maintenance products, such as caulk or roofing tar; or
o) Bringing freshly dry-cleaned clothing or furnishings into the building.

2.10.2 Product Inventory

The primary objective of the product inventory is to identify potential air sampling interference by characterizing the occurrence and use of chemicals and products throughout the building, keeping in mind the goal of the investigation and site-specific contaminants of concern. For example, it is not appropriate to provide detailed information for each individual container of like items. However, it is appropriate to indicate that “20 bottles of perfume” or “12 cans of latex paint” were present with containers in good condition. This information is used to help formulate an indoor environment profile.

An inventory should be provided for each room on the floor of the building being tested and on lower floors, if possible. This is important because even products stored in another area of a building can affect the air of the room being tested. The presence and description of odors (e.g., solvent, moldy) and portable vapor monitoring equipment readings (e.g., PIDs, ppbRAE, Jerome Mercury Vapor Analyzer) should be noted and used to help evaluate potential sources. This includes taking readings near products stored or used in the building. Where applicable, readings should be provided in units that denote the calibration gas (e.g., isobutylene-equivalent ppm, benzene-equivalent ppm).

Products in buildings should be inventoried every time indoor air is tested to provide an accurate assessment of the potential contribution of volatile chemicals. If available, chemical ingredients of interest (e.g., compound list) should be recorded for each product. If the ingredients are not listed on the label, record the product's exact and full name and the manufacturer's name, address, and telephone number, if available. In some cases, material Safety Data Sheets may be useful for identifying confounding sources of volatile chemicals in air.

Adequately documented photographs of the products and their labeled ingredients can supplement the inventory and facilitate recording the information.

2.11 Role of Modeling

At sites where there is a likely human exposure to subsurface contamination due to soil vapor intrusion (as described in Section 2.1), the use of modeling as the sole means of evaluating potential exposures should be avoided. The limitations of modeling (e.g., exclusion of preferential migration pathways), introduce uncertainty as to whether human exposure is occurring, in absence of actual field data. Conclusions drawn from modeling must be verified with actual field data. For example, if modeling results indicate indoor air concentrations are predicted to be below applicable guidelines or levels of concern, indoor air and/or sub-slab vapor sampling would be appropriate to verify a conclusion that mitigation or other actions are not needed.

Modeling may, however, be used as a tool in the evaluation process. Examples of situations in which modeling may be used as a tool include, but are not limited to, the following:

a) To help identify potential migration pathways on the basis of site-specific conditions;
b) To estimate potential exposures when field samples cannot be collected (e.g., buildings have not yet been constructed over the subsurface contamination); and
c) To identify a preferred order for sampling buildings, by predicting expected indoor air concentrations within each of the buildings if there are numerous buildings overlying the subsurface contamination.

Use of any model at a site should be discussed with the MDEQ prior to the model's development and application. If a model is used, it should incorporate site-specific parameters (e.g., attenuation factors, soil conditions, concentrations of volatile chemicals, depth to subsurface source, characteristics of subsurface source, and foundation slab thickness), as much as possible.

Furthermore, both the limitations of the model (e.g., exclusion of preferential migration pathways), and the sensitivity of the variables in the model should be understood and identified with the modeling results.

3. DATA EVAULTION AND RECOMMENDATIONS FOR ACTION

Section 3 describes the process by which data obtained during the investigation are evaluated. The goals of the evaluation are to determine what volatile chemicals, if any, are present in the investigated media, to identify the likely cause(s) of their presence, and to identify existing and potential human exposures and whether actions to address exposures should be taken.

Also discussed are actions typically recommended based on the evaluation. Actions to remediate the source(s) of soil vapor contamination, such as soil excavation or air sparge/soil vapor extraction systems, may be appropriate response actions but are beyond the scope of this guidance.

Before the data is evaluated, their representativeness and reliability should be verified. To assess analytical errors and the usability of the data, a qualified person should review the analytical data package and all associated QA/QC information to make sure that:

a) The data package is complete;
b) Holding times have been met;
c) The quality control data fall within the protocol limits and specifications;
d) The data have been generated using established and agreed upon analytical protocols;
e) The raw data confirm the results provided in the data summary sheets and quality control verification forms; and
f) Correct data qualifiers have been used.

If the investigation was not completed in accordance with the guidelines set forth in Section 2, additional investigation may be appropriate to either replace or complement the existing data. For example, product inventories [Section 2.10.2] filled out incompletely or incorrectly may need to be redone (and in some cases with additional indoor air sampling), so that potential sources of volatile chemicals in the indoor air can be identified and a determination of whether soil vapor requires actions to mitigate exposures.

3.1 Overview

The results of individual soil vapor, sub-slab vapor, indoor air and outdoor air samples are not reviewed in isolation. Rather, they are evaluated with the consideration of several additional factors, which include all of the following:

a) The nature and extent of contamination in **all** environmental media;
b) Factors that affect vapor migration and intrusion;
c) Remedial actions;
d) Sources of volatile chemicals;
e) Relevant standards, criteria, and guidance values; and
f) Past, current, and future land uses.

These factors are described in detail in this subsection.

3.1.1 Nature and Extent of Contamination in All Environmental Media

The type of volatile chemicals present and the extent of contamination in all environmental media including soil, groundwater, subsurface vapors, indoor air, and outdoor air is considered when evaluating the data. Trends in environmental data (e.g., groundwater monitoring results show concentrations of volatile chemicals are decreasing) are also considered. This information is used to identify possible sources of contamination and migration pathways, as well as to recommend appropriate actions to address exposures.

3.1.2 Factors That Affect Vapor Migration and Intrusion

As discussed in Section 1.3, there are numerous site-specific environmental factors [Table 1.1] and building factors [Table 1.2] that can affect soil vapor migration and intrusion. This information is used to identify possible sources of contamination and migration pathways, as well as to recommend appropriate actions to address exposures.

3.1.3 Sources of Volatile Chemicals

An understanding of the likely sources of the chemicals is crucial for determining appropriate actions to address exposure, as well as identifying the parties responsible for implementing the

actions. Volatile chemicals that are not site-related may be present in the investigated media for reasons such as the following:

a) *Subsurface vapors* — misuse, misapplication, or improper disposal of the chemicals to the subsurface, unidentified subsurface sources of vapor contamination, presence of septic systems (where products, such as cleaning agents or degreasers, may be disposed), biodegradation of natural organic matter in soil, infiltration into the subsurface from a building under positive pressure in which the chemicals are heavily used (i.e., reverse process from soil vapor intrusion);
b) *Indoor air* — use and storage (current or historic) of volatile chemical containing products, off-gassing from building materials or new furnishings, use of contaminated groundwater during private well usage, infiltration of outdoor air containing volatile chemicals [Table 1.3]; or
c) *Outdoor air* — emissions from automobiles, lawn mowers, oil storage tanks, gasoline stations, dry cleaners, or other commercial/industrial facilities [Table 1.3].

Site-related chemicals may also be present for these same reasons. Information about household products and their ingredients are available on web sites, such as the National Institute of Health's website at: http://householdproducts.nlm.nih.gov.

3.1.4 Concentrations of Volatile Chemicals in Ambient Air

Chemicals are part of our everyday life [Section 1.5]. As such, they are found in the indoor air of buildings not affected by intrusion of contaminated soil vapor. They are also found in the outdoor air that enters a home or place of business.

3.1.5 Relevant Standards, Criteria, and Guidance Values

The purpose of a guidance document is to help assist in the decision-making process. The goal of the recommended actions is to prevent the infiltration of vapors from the subsurface. Reasonable and practical actions should be taken to reduce exposures when indoor air levels are above background, even when they are below the published guidance values. The urgency to complete any type of mitigation or remedial actions increases as concentrations in the indoor air are detected above the AIACs and even more when they exceed acute values. In all cases, the specific corrective actions to be taken depend on a case-by-case evaluation of the situation.

As stated in Section 1, the MDEQ has developed the ASGSCs for use in evaluating the volitalization to indoor air pathway and also in cases where the generic criteria do not apply. Though a site-specific evaluation may be conducted, the ASGSCs have been provided for further assistance.

3.1.6 Implementation of Remedial Actions

The status and effectiveness of actions taken to remediate environmental contamination (e.g., soil removal, groundwater treatment, soil vapor extraction), are considered when making decisions pertaining to additional sampling and the selection of mitigation actions. For example:

a) If a comparison of pre-remediation and post-remediation subsurface vapor sampling results indicate negligible improvement in the quality of subsurface vapors,
   - additional sampling may be appropriate to document a decreasing trend in subsurface vapor concentrations;
   - termination of mitigation system operations may not be appropriate without additional sampling; or
   - additional remedial actions may be appropriate to address contaminated subsurface vapors.

b) When ongoing monitoring of a building is necessary to assure risks are not present, it may be more cost effective to install a mitigation system if subsurface contamination is wide spread and is expected to take many years to attenuate; and

c) If exposures in an on-site building will be addressed concurrently by a method selected to remediate subsurface contamination (e.g., a soil vapor extraction system), installation of a mitigation system may be redundant. However, if the remedial system is not expected to be operational in the immediate future, or if it is not expected to mitigate indoor air levels in a reasonable time frame, a mitigation system may still be appropriate. [Refer to Section 4 for a description of the appropriate use of concurrent techniques.]

3.1.7 Past, Current, and Future Land Uses

Past, current, and future land uses are considered when evaluating the investigation data and determining appropriate actions for further investigation, or measures to address exposures. For example, if the parcel or buildings were historically used for commercial or industrial purposes (e.g., gasoline station, automotive repair facility, electroplating facility), but are currently used for residential purposes, commercial, or industrial purposes where volatile chemicals are not used in current operations, off-gassing of volatile chemicals from building materials [Table 1.3] or additional subsurface sources should be considered.

Subsurface vapor sampling of a parcel that is undeveloped or contains unoccupied buildings may be appropriate based on the data evaluation. If actions should be taken to mitigate exposures related to soil vapor intrusion if the site is developed, the appropriate mitigation method will depend upon the proposed land use, i.e., a parking lot, recreational field, single-family home, commercial building, high-rise building with underground parking, occupied or unoccupied building, since each presents a different exposure scenario.

3.2 Sampling Results and Recommended Actions

This subsection describes the process for evaluating sampling results. It also describes actions that may be recommended based on the evaluation. The evaluation procedures and actions described may not be directly applicable to samples collected as part of an emergency response.

3.2.1 Soil Vapor

If soil vapor samples are collected from locations where there are no known sources of volatile chemicals, the MDEQ does not expect the chemicals to reach detectable levels in the samples. However, sources of vapor including groundwater, soil, and free phase saturated soils, exist a significant distance from their extent of detection in the soil gas sample. Therefore, soil vapor sampling results must be reviewed "as a whole," in conjunction with the results of other environmental sampling and the CSM, to identify trends and spatial variations in the data [Section 3.2.1].

Comparisons are used to:

a) Identify areas of relatively elevated concentrations of volatile chemicals in soil vapor;
b) Select buildings for sub-slab vapor, indoor air, and outdoor air sampling;
c) Select buildings for mitigation;
d) Identify possible sources of subsurface vapor contamination;
e) Monitor the progress, or verify the completion of efforts to remediate subsurface vapor contamination (either directly or indirectly); and
f) Characterize the nature and extent of subsurface vapor contamination.

When determining appropriate actions, soil vapor results may not indicate a traditional plume-like pattern of contamination (as is often described for groundwater). Rather, the nature and extent of contamination may follow a "hit and miss" pattern. Our experience, to date, indicates soil vapor results alone typically cannot be relied upon to rule out sampling at nearby buildings. For example, concentrations of volatile chemicals in sub-slab vapor samples have been substantially higher (e.g., by a factor of 100 or more) than concentrations found in nearby soil vapor samples (e.g., collected at eight feet below grade near the building). This may be due to differences in factors such as soil moisture content and pressure gradients. Therefore, exposure risks are evaluated primarily based on sub-slab vapor, indoor air, outdoor air sampling results, and soil vapor results are primarily used as a tool to guide the sub-slab investigations.

The following actions may be indicated based on sample results:

a) *No further soil vapor sampling* – The sampling frequency, locations, and methods comply with those identified in Section 2, and no concentrations have been detected above the ASGSCs.
b) *Additional soil vapor sampling* – Additional characterization of the nature and extent of subsurface vapor contamination is necessary to:
   - Verify sampling results with previous sampling and/or the current understanding of the site [Sections 3.2.1 and 3.2.2];
   - Monitor the progress, or verify the success, of efforts to remediate subsurface vapor contamination (either directly or indirectly);
   - Identify possible sources of subsurface vapor contamination; or
   - Resample locations where results may have been invalidated by short-circuiting (outdoor air infiltration), cross contamination, or other problems.
c) *Conduct sub-slab vapor and indoor air sampling* – Generally, if soil vapor results are fairly consistent throughout the study area, buildings closest to the source area are sampled first. The investigation should proceed outward, as appropriate, on an areal basis until potential and current human exposures have been adequately identified. If there is an area of relatively elevated concentrations of volatile chemicals in soil vapor (when looking at the soil vapor results as a whole), then the buildings in these areas should be sampled to assess if immediate mitigation is required.
d) *Address exposures related to soil vapor intrusion* – Land use and/or deed restriction may be appropriate so that the parcel will not be developed or buildings occupied without addressing exposure concerns [Sections 2.3 and 3.6]. As discussed previously, soil vapor sampling can guide sampling efforts in buildings. However, a "blanket mitigation" approach may be taken, provided the nature and extent of soil vapor contamination has been sufficiently characterized.

NOTES

1. The recommended actions above may be modified or based upon factors given in Section 3.
2. Additional sampling may become appropriate based on the migration of subsurface contamination (e.g., contaminated groundwater or vapors) or if environmental monitoring indicates a change in chemical constituents has occurred (e.g., the production of degradation products that may be more toxic than the parent compounds).

3.2.2 Sub-slab Vapor

The goals of collecting sub-slab vapor samples are to identify potential and current (when collected concurrently with indoor and outdoor air samples), exposures associated with soil vapor intrusion, and to characterize the nature and extent of subsurface vapor contamination. The detection of volatile chemicals in sub-slab vapor samples indicates soil vapor intrusion is occurring; and actions should be taken to address exposures.

Based on this evaluation, the following actions may be recommended:

a) *No further action* — When the volatile chemical is not detected in the sub-slab sample above the ASGSCs, results are not expected to affect indoor air quality. Sampling will need to continue until adequate sampling results have been obtained [see Section 2].
b) *Take reasonable and practical actions to identify source(s) and reduce indoor air exposures* — In cases where indoor air samples are collected, concentrations are detected in the indoor air sample, and not in the sub-slab or soil gas samples, it is likely due to indoor and/or outdoor sources rather than vapor intrusion. Therefore, steps should be taken to the occupants, as part of the sampling reporting, to identify potential source(s) and to identify ways to reduce exposures accordingly (e.g., by keeping containers tightly capped or by storing volatile organic compound-containing products in places where people do not spend much time, such as a garage or outdoor shed). Resampling may be appropriate to demonstrate the effectiveness of actions taken to reduce exposures.
c) *Resampling* — Resampling may also be recommended when the results are not consistent with the CSM. For example, when the sub-slab vapor results of a building do not indicate a need to take action, but the sub-slab vapor results of adjacent buildings indicate a need to take actions to address exposures related to soil vapor intrusion. Resampling may be appropriate if samples were collected outside of the heating season. Multiple sampling rounds will be required to rule out exposures related to soil vapor intrusion [see Section 2].
d) *Monitoring* — Monitoring, including sub-slab vapor, basement air, lowest occupied living space air, and outdoor air sampling, may be recommended to determine whether concentrations in indoor air or sub-slab vapor have changed. It also may be part of a program to determine what affect, if any, active soil and groundwater remediation techniques (e.g., chemical oxidation, air sparging), may be having on subsurface vapor and indoor air quality. The type and frequency of monitoring is determined on a site-specific and building-specific basis, taking into account applicable environmental data and building operating conditions.
e) *Mitigate* — Mitigation may be appropriate to minimize current or potential exposures associated with soil vapor intrusion. Mitigation methods are described in Section 4.

NOTES

1. The recommended actions above may be modified based upon factors given in Section 3.2.
2. Additional sampling may be appropriate based on the migration of subsurface contamination (e.g., contaminated groundwater or vapors), or if environmental monitoring indicates a change in chemical constituents has occurred (e.g., the production of degradation products that may be more toxic than the parent compounds).
3. Monitoring and mitigation measures to address exposures related to soil vapor intrusion are considered interim measures implemented until contaminated environmental media (e.g., soil, groundwater, and/or soil vapor) are remediated or naturally attenuate.

4. Presumptive actions protective of human health may be proposed. For example, such a decision may be based on a comparison of the costs associated with resampling or monitoring to the costs associated with installation and monitoring of a mitigation system.
5. Additional sampling associated with post-mitigation testing, operation maintenance monitoring activities, and termination of mitigation system operations is described in Section 4.

3.2.3 Indoor Air

Indoor air samples are used to assess current exposures to volatile chemicals in air. The detection of volatile chemicals in indoor air samples does not necessarily indicate soil vapor intrusion is occurring or actions should be taken to address exposures.

When evaluating indoor air data, the results are compared to outdoor air, the soil gas concentrations, and human health risks (i.e., cancer and non-cancer health effects) associated with exposure to the volatile chemical in air. This helps to put the results into perspective and to determine the need for action and the urgency with which actions should be taken. As discussed, the urgency to complete reasonable and practical actions to reduce exposures increases with indoor air levels, particularly when air levels are above the ASGSCs and are near or above acute concentrations.

Additional sampling may be appropriate if:

a) Samples were collected at times when vapor intrusion is not expected to have its greatest effect on indoor air quality. As discussed in Section 2.4, these results may not be used to rule out exposures related to soil vapor intrusion.
b) The potential for exposures related to soil vapor intrusion should be monitored based on the sub-slab vapor results [Section 3.3.2].
c) Subsurface conditions change over time (e.g., due to the migration of contaminated groundwater or vapors).

Volatile chemicals may be present in the indoor air due to any one, or a combination, of the following:

a) The indoor environment itself and/or building characteristics;
b) Off-gassing of volatile chemicals from contaminated water that rests in a sump, subsurface drain, during flooding events, or that enters the building at the tap or shower head;
c) Outdoor sources; and/or
d) Migration from the subsurface (i.e., soil vapor intrusion).

To determine the likely cause, the following assessment needs to be completed:

a) Qualitative and quantitative comparisons are made between the types and concentrations of the contaminants found in the indoor air sample(s) and those found in the sub-slab vapor sample;
b) Qualitative and quantitative comparisons are made between indoor air results obtained in different locations of the building (e.g., different floors or rooms);
c) Indoor air results are compared to the product inventory to evaluate the extent to which indoor sources are affecting indoor air quality; and
d) The indoor air quality questionnaire and building inventory form is reviewed to identify potential preferential pathways for soil vapor intrusion into the building, potential outdoor sources of volatile chemicals to the outdoor air (e.g., gasoline station or dry cleaner), and routes of air distribution within the building (e.g., HVAC system operations, airflow observations).

If a likely source or multiple sources can be identified from the available information, one or more of the following actions may be recommended given the source:

a) *Indoor source or building characteristics* ─ Products containing volatile chemicals should be tightly capped. Alternatively, the products can be stored in places where people do not spend much time, such as a garage or outdoor shed. If the products are no longer needed, consideration should be given to disposing of them properly (e.g., hazardous waste cleanup days). The list of products and corresponding readings from field instrumentation provided in the product inventory [Appendix C] can help identify products that may be contributing to the levels that were detected in the indoor air. If exposures are assumed to be associated with off-gassing of new building materials, paint, resampling may be appropriate to confirm this assumption or to confirm that actions taken to address these exposures have been effective.
b) *Off-gassing from contaminated groundwater within the building* ─ Measures should be taken to prevent contaminated groundwater from entering the house (e.g., filter on private well supply, direct vent of sump, sealed sump).
c) *Outdoor source* ─ No further action to address exposures related to soil vapor intrusion are required if sub-slab samples are not impacted.
d) *Soil vapor intrusion* ─ Depending upon the relationship between indoor air concentrations and sub-slab vapor concentrations and the results of environmental sampling in the area, resampling, monitoring or mitigation may be recommended by the MDEQ. For example:
    - Resampling, including sub-slab vapor, basement air, lowest occupied living space air, and outdoor air sampling, may be recommended when the results are not consistent with the CSM. For example, when indoor air results are comparable or higher than the corresponding sub-slab vapor results and the results do not appear to be due to building characteristics or alternate sources (either indoor or outdoor).

- Monitoring, including sub-slab vapor, basement air, lowest occupied living space air, and outdoor air sampling, may be recommended to determine whether concentrations in indoor air or sub-slab vapor have changed. It is also recommended to determine what affect, if any, active soil and groundwater remediation techniques (e.g., chemical oxidation, air sparging) may be having on subsurface vapor and indoor air quality. The type and frequency of monitoring is determined on a site-specific and building-specific basis, taking into account applicable environmental data and building operating conditions.
- Methods to mitigate exposures related to soil vapor intrusion are described in Section 4.

The party responsible for implementing the recommended actions will differ depending upon several factors, including the identified source of the volatile chemicals, the environmental remediation program, and site-specific and building-specific conditions. In some circumstances, likely sources of the indoor air contamination may not be evident given the information available. In these situations additional information is necessary to determine appropriate actions. This situation most often arises for the following reasons:

a) Interfering indoor sources are identified. However, the possibility of vapor intrusion cannot be ruled out due to the concentrations of the same volatile chemicals detected in the sub-slab vapor sample. Differentiating the contribution of each source is not possible.
b) Indoor air samples were collected without concurrent outdoor air and sub-slab vapor samples. Identifying likely sources and recommending appropriate actions may not be possible.
c) All appropriate air samples are collected. However, the indoor air quality questionnaire and building inventory forms are filled out incompletely or incorrectly. The contribution of indoor sources cannot be evaluated.
d) All appropriate sub-slab and indoor air samples are not collected.

3.2.4 Outdoor Air

Outdoor air sampling results are primarily used to evaluate the extent to which outdoor air may be contributing to the levels of volatile chemicals detected in indoor air or to identify the vapors if sub-slab or soil gas samples do not contain any VOCs.

3.3 Decision Matrices

A decision matrix is a risk management tool developed to provide guidance on a case-by-case basis about actions that should be taken to address current and potential exposures related to soil vapor intrusion. The MDEQ has developed two matrices to assist in evaluation of the volatilization pathway.

3.3.1 Decision Matrix for Determining Appropriate and Acceptable Sampling Strategies for Assessment of Indoor Air Risk

The MDEQ has developed a decision matrix (Appendix A) that summarizes appropriate and acceptable sampling strategies for assessing indoor air risk.

3.3.2 Sub-slab Results Decision Matrix for Appropriate Response Actions

The sub-slab results decision matrix is intended to be used when evaluating the results from a properly conducted sub-slab sampling program. The matrix encapsulates the data evaluation processes and actions recommended to address exposures.

Sub-slab vapor concentration ranges in the matrix are selected based on a number of considerations in addition to health risks. For example, factors that are considered when selecting the ranges include, but are not limited to, the following:

a) Human health risks, including such factors as a chemical's ability to cause;
b) Cancer, reproductive, developmental, liver, kidney, nervous system, immune system or other effects in animals and humans, and the doses that may cause those effects associated with exposure to the volatile chemical in air (i.e., cancer and non-cancer health effects);
c) The data gaps in its toxicological database;
d) Analytical capabilities currently available; or
e) Expected attenuation factors (i.e., the ratio of indoor air to sub-slab vapor concentrations).

The matrix has been developed and should be used as a preliminary evaluation tool. Actions recommended in the matrix are based on sub-slab vapor concentrations. They are intended to address both potential and current human exposures and generally result in one of the following determinations:

a) *No further action* — When the volatile chemical is not detected or when detected in the corresponding sub-slab vapor sample, it is not expected to substantially affect indoor air quality.
b) *Monitor* — Monitoring of sub-slab vapor is appropriate to determine whether concentrations in the sub-slab vapor have changed. Monitoring may also be appropriate to determine whether existing building conditions (e.g., positive pressure HVAC systems) are maintaining the desired mitigation endpoint and to determine whether changes are appropriate. The type and frequency of monitoring is determined on a site-specific and building-specific basis, taking into account applicable environmental data and building operating conditions.
c) *Monitor/Mitigate* — Continued monitoring of the sub-slab soil gas or mitigation may be recommended after considering the magnitude of sub-slab vapor and indoor air concentrations along with building and site-specific conditions.

d) *Mitigate* – Mitigation is appropriate to minimize current or potential exposures associated with soil vapor intrusion. Methods to mitigate exposures related to soil vapor intrusion are described in Section 4.

Table 3.1 – Sub-slab Results Decision Matrix for Appropriate Response Actions

Sub-slab Vapor Concentration of Volatile Chemical ($\mu g/m^3$)	Appropriate Response Action
< AIAC	No mitigation required, with proper sampling no further action may be warranted.
AIAC < ASGSC	Monitor sub-slab concentrations, if concentrations continue to approach the ASGSCs a more detailed sampling approach is warranted
> ASGSC	Mitigate sub-surface vapors
> 10 x ASGSC (or the concentration is expected to exceed the acute indoor air concentration)	Immediately implement mitigation measures and confirm mitigation measures through Indoor Air Monitoring

3.4 Emergency Response

Indoor air sampling is appropriate in some cases for demonstrating that spill cleanup, assessing acute risks, and evaluating whether engineering controls have been effective in reducing indoor air impacts and associated health risks. At a minimum, air samples are collected from the basement, first floor, and from outdoors. Whether sub-slab or soil gas samples will be taken is evaluated on a case-by-case basis.

3.5 Parcels that are Undeveloped or Contain Unoccupied Buildings

If the investigation of a parcel that is undeveloped or contains unoccupied buildings is being delayed until the site is being developed or occupied, measures should be in place to assure that no development or occupation will occur without addressing the exposures. The ICs must limit human exposure and provide notice to potential owners, operators, or members of the public.

If ICs are not implemented, alternative measures should be in place that assure the MDEQ that the parcel will not be developed or buildings occupied without addressing the exposure concerns.

4. VAPOR MITIGATION

Soil vapor can enter a building through cracks, perforations in slabs or basement floors and walls, through openings around sump pumps, or where pipes and electrical wires go through the foundation primarily because of a difference between interior and exterior pressures [Section 1.1]. This intrusion is similar to how radon gas enters buildings from the subsurface. Fortunately, given this similarity, well established techniques for mitigating exposures to radon may also be used to mitigate exposures related to soil vapor intrusion.

Once it is determined that steps should be taken to address exposures associated with soil vapor intrusion or a presumptive implementation will be pursued, they should be implemented with all due expediency. This section provides an overview of:

a) Methods of mitigation,
b) Installation and design of mitigation systems,
c) Post-mitigation testing,
d) Operation, maintenance, and monitoring of mitigation systems,
e) Termination of mitigation system operations, and
f) Documentation of compliance with the Michigan Air Pollution Control Rules.

Vapor mitigation systems are considered engineering controls that are employed to actively or passively contain, stabilize or monitor vapors, restrict the movement of vapors to ensure the long-term effectiveness of remedial actions, or eliminate potential exposure pathways to any vapors.

Mitigation is considered to be an appropriate measure to address exposures until contaminated environmental media are remediated, or until mitigation is no longer needed to address exposures related to soil vapor intrusion. In all cases where mitigation is being considered the system should be designed to function under a variety of scenarios. The

"primary" mitigation system must be capable of preventing any vapors from the subsurface entering into the structure and must function independently of any other site activity. In most cases the system will have additional components installed that will function independently of the primary system and allow for the system to remain effective for short durations of time during periods that the primary system is off-line.

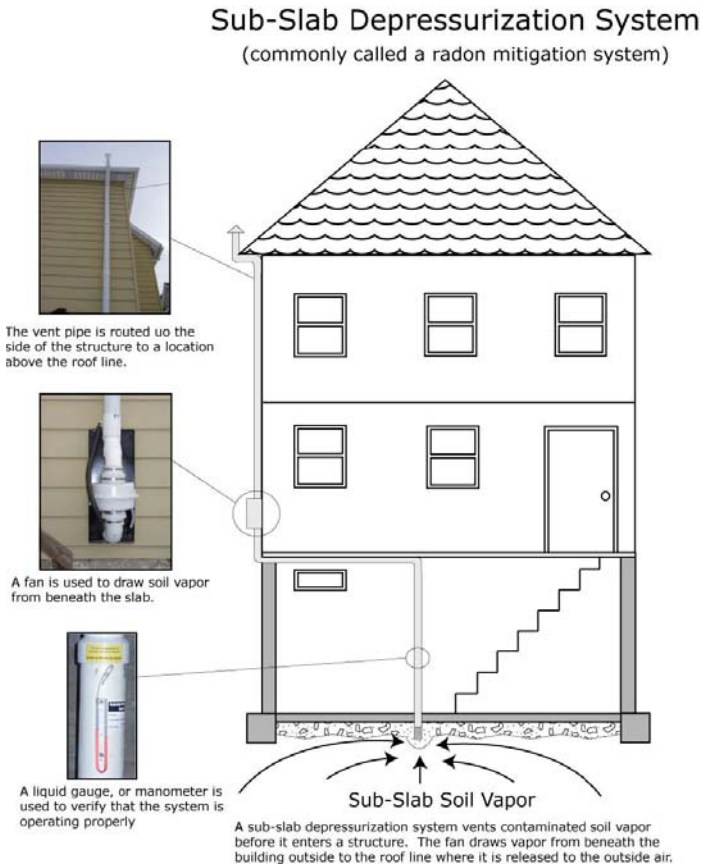
4.1 Methods of Mitigation

The most effective mitigation methods involve sealing infiltration points and actively manipulating on a continuous basis the pressure differential between the building's interior and exterior. As discussed in the following subsections, the appropriate method to use will largely depend upon the building's foundation design. Furthermore, buildings having more than one foundation design feature (e.g., a basement under one portion of the house and a crawl space beneath the remainder) may require a combination of mitigation methods. This section describes methods of mitigation that are expected to be the most reliable options under a wide range of circumstances. Occasionally, there are site-specific or building-specific conditions under which alternative methods (such as HVAC modification, sealing, room pressurization, passive ventilation systems, or vapor barriers) may be more appropriate. Such mitigation proposals may be considered on a case-by-case basis.

4.1.1 Buildings with a Basement Slab or Slab-on-Grade Foundation

In conjunction with *sealing* potential subsurface vapor entry points, an active SSD provides a mitigation method for buildings with a basement slab or slab-on-grade foundation. An SSD uses a fan-powered vent and piping to draw vapors from the soil beneath the building's slab (i.e., essentially creating a vacuum beneath the slab), and discharges them to the atmosphere. This results in lower sub-slab air pressure relative to indoor air pressure, which prevents the infiltration of sub-slab vapors into the building. All active SSD*'s* are required to meet the exemptions identified in the Michigan Air Pollution Control Rules [Section 4.6]. A generic SSD is depicted in Figure 4.1.

Figure 4.1
Example of how an SSD system works.



The most common approach to achieving depressurization beneath the slab is to insert the piping through the floor slab into the crushed rock or soil underneath. However, the U.S. EPA, in their "Consumer's Guide to Radon Reduction" (U.S. EPA 402-K-03-002; revised February 2003), lists the following approaches that are appropriate for soil gas vapor intrusion mitigation. The approaches reduce radon levels in a building, either in place of the more common sub-slab suction point method or in conjunction with that method:

a) *Drain tile suction* — Some structures have drain tiles or perforated pipe to direct water away from the foundation. Suction on these tiles or pipes can be effective.
b) *Sump hole suction* — If the building has a sump pump to remove unwanted water, the sump can be capped so that it can continue to drain water and serve as the location for piping. If the sump is not used as the suction or extraction point, the associated wiring and piping should be sealed, and an air-tight cover should be installed to enhance the performance of the SSD and ensure that vapors are not entering the structure via the sump.

c) *Block wall suction* — If the building has hollow block foundation walls, the void network within the wall may be depressurized by drawing air from inside the wall and venting it to the outside. This method is often used in combination with sub-slab depressurization.

The depressurization approach, or combination of approaches selected for a building should be determined on a building-specific basis, due to building-specific features that may be conducive to a specific depressurization approach. For example, if the contaminants are entering the building through a block wall, block wall suction in conjunction with traditional sub-slab depressurization may be more effective at minimizing exposures related to soil vapor intrusion rather than sub-slab depressurization alone.

Although most sealants are not a reliable mitigation technique on their own, they can significantly improve the effectiveness of an SSD since it limits the flow of subsurface vapors into the building. All joints, cracks and other penetrations of slabs, floor assemblies and foundation walls below or in contact with the ground surface should be sealed with materials that prevent air leakage.

Other alternative mitigation methods may be considered, such as the following:

a) *HVAC modification* — A technique where the building's HVAC system is modified to avoid depressurization of the building relative to underlying and surrounding soil (i.e., to maintain a positive pressure within the building). This method or technique cannot be used as a primary mitigation method and may be only applicable in limited circumstances.
b) S*VE system* — A technique used to remediate contaminated subsurface soil vapor. The SVE systems use high flow rates, induced vacuum, or both to collect and remove contamination, while the SSD uses a minimal flow rate to effect the minimum pressure gradient (see the U.S. EPA's technical guidance documents for recommended gradients) needed to reverse air flow across a building's foundation [see Section 4.2.3]. Depending upon the SVE system's design, the system may also serve to mitigate exposures. For example, the SVE system's radius of influence includes the subsurface beneath affected buildings or horizontal legs of the system that will be installed beneath affected buildings. Though the capital cost for an SVE system may be initially more expensive, under most long-term cost evaluations its ability to address the source of the vapors will lend itself to significant long term cost savings.
c) *Vapor barrier with a passive SSD* — A vapor barrier (as compared to a vapor retarder), is installed over the lowest foundation level in combination with a passive SSD. Often this will require the installation of a “useable” surface above and over the entire vapor barrier. In addition, building codes in an area may limit their use. The vapor barrier must be chemical resistant and have a rating for the chemical of interest less than .2 perms.

4.1.2 Buildings with a Crawl Space Foundation

A soil vapor retarder with an SMD system is a mitigation method for buildings with a crawl space foundation. A soil vapor retarder is a synthetic membrane or other comparable material that is placed on the ground in the crawl space to retard the flow of soil vapors into the building. An SMD is similar to an SSD. It uses a fan-powered vent and piping to draw vapors from beneath the soil vapor retarder and discharge them into the atmosphere. This results in lower air pressure beneath the membrane relative to air pressure in the crawl space, which prevents the infiltration of subsurface vapors into the building.

Other alternative mitigation methods that may be considered, such as the following:

a) *HVAC modification* — A technique where the building's HVAC system is modified to avoid depressurization of the building relative to the crawl space. This method cannot be used as a primary mitigation method and may be only applicable in limited circumstances.
b) C*rawl space ventilation with sealing* — A technique that uses a fan to draw air out of the crawl space.
c) *SVE system* [Section 4.1.1].

4.1.3 Buildings with Dirt Floor Basements

Either an SSD with a newly poured slab or SMD with a soil vapor retarder may be used. Though an SMD with a soil vapor retarder may be more effective, depending on the construction and the material utilized, it may also make the area unusable for storage due to the risks associated with puncturing the membrane.

4.1.4 Buildings with Multiple Foundation Types

Mitigation in a building with a combination of foundations should be achieved by applying the specific methods described previously [Sections 4.1.1 through 4.1.3] to the corresponding foundation segments of the building. Special consideration should be given to the points at which different foundation types join, since additional soil vapor entry routes exist in such locations. Often, the various systems can be installed and connected to a common depressurization system and fan.

4.1.5 Undeveloped Parcels

If sampling results indicate a mitigation system is recommended to address exposures in buildings that may be constructed, then an SSD with sealing, or an SMD with a soil vapor retarder, may be used, as appropriate to the design of the proposed buildings. Based on evaluating multiple case studies cost analysis proposals it is clear that providing a true vapor barrier, not a vapor retarder, in conjunction with a passive SSD when designed correctly is both protective and cost efficient. Multiple products are available on the market for consideration.

Evaluation of the vapor retarder should include:

a) Permeability (must be low);
b) Longevity (does not decompose);
c) Puncture resistance in order to continue with the site construction activities; and
d) Installation efficiency.

The ASTM standards that should be consulted to evaluate various vapor barriers include the following (by number and not order of importance):

- ASTM E96/E96M-05 Standard Test Methods for Water Vapor Transmission of Materials.
- ASTM D412-06a Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension.
- ASTM D543-06 Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents.
- ASTM D1434-82 (2003) Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting
- ASTM E 1745-97 “Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs”.

4.2 Design and Installation of Mitigation Systems

The components of the design and installation of mitigation systems, the procedures for specific mitigation techniques, and references for technical guidance are provided in the following subsections.

4.2.1 General Recommendations

Systems should be designed and installed by a professional engineer or environmental professional. For a “radon-like” system, in most areas of the State of Michigan, there are contractors who are trained to identify and fix radon problems in buildings that should be able to assist in the design. Sealants and other methods may require specific contractors with the assistance of a professional engineer or environmental professional to design and install.

All design and installation activities should be documented. Furthermore, once a mitigation system is installed, an information package must be provided to the building's owner and tenants, if applicable, to facilitate their understanding of the system's operation, maintenance and monitoring.

With the exception of SVE systems, the mitigation methods introduced in Section 4.1 are not intended to remediate the source of subsurface vapors (e.g., contaminated groundwater, soil). Rather, they are designed to minimize the infiltration of subsurface vapors into a building.

4.2.2 System-specific Recommendations

Basic design and installation recommendations for mitigation systems follow. These are based upon recommendations and requirements provided by the U.S. EPA for mitigating exposures related to radon intrusion (for additional information see the U.S. EPA's web site on radon at http://www.epa.gov/iaq/radon/pubs/index.html).

a) *Sealing* — To improve the effectiveness of depressurization and ventilation systems and to limit the flow of subsurface vapors into the building, materials that prevent air leakage should be used, such as electrometric joint sealant (as defined in ASTM C92087), compatible caulks, non-shrink mortar, grouts, expanding foam, "Dranjer" drain seals, or airtight gaskets. Some effective sealants may contain VOCs and in some situations, this may be a consideration in choosing an appropriate sealing material.

b) *Soil vapor retarder (membrane)* — To retard the infiltration of subsurface vapors into the building and enhance the performance of an SMD, a minimum six mil (or three mil cross-laminated), polyethylene or equivalent flexible sheeting material should be used. It must cover the entire floor area and be sealed at seams (with at least a 12 inch overlap) and penetrations, around the perimeter of interior piers, and to the foundation walls.

   Enough of the sheeting should be used so it will not be pulled away from the walls when the depressurization system is turned on and the sheet is drawn down.

   If a membrane is installed in areas that may have future foot traffic (e.g., a dirt floor in a basement), consideration should be given to also installing a wearing surface such as sand or stone to protect the integrity of the membrane. Additionally, a layer of fine sand may be prudent beneath the membrane to protect it from penetrations by sharp objects in the dirt floor.

c) *Depressurization systems* —
   - The systems should be designed to avoid the creation of other health, safety, or environmental hazards to building occupants (e.g., back drafting of natural draft combustion appliances).
   - The systems should be designed to minimize soil vapor intrusion effectively while minimizing excess energy usage, to avoid compromising moisture, temperature controls and other comfort features, and to minimize noise.
   - To evaluate the potential effectiveness of an SSD before it is installed, a diagnostic test (commonly referred to as a “communication” test) should be performed to measure the ability of a suction field and air flow to extend through the material beneath the slab. This test is commonly conducted by applying suction on a centrally located hole drilled through the concrete slab and simultaneously observing the movement of smoke downward into small holes drilled in the slab at locations separated from the central suction hole. A similar quantitative evaluation may also

be performed by using a digital micromanometer or comparable instrument. Depending on test results, multiple suction points may be needed to achieve the desired effectiveness of the system.

- Passive systems (i.e., an SSD without a vent fan) are not as effective as active systems, and their performance varies depending upon ambient temperatures and wind conditions. In most cases an active system will be required unless a soil vapor barrier can be installed and maintained that is documented to be resistant to VOC vapor migration.
- The vent fan and discharge piping should not be located in or below a livable or occupied area of the building to avoid entry of extracted subsurface vapors into the building in the event of a fan or pipe leak.
- To avoid entry of extracted subsurface vapors into the building, the vent pipe's exhaust should be:
  - above the eave of the roof (preferably, above the highest eave of the building at least 12 inches above the surface of the roof);
  - at least ten feet above ground level;
  - at least ten feet away from any opening that is less than two feet below the exhaust point; and
  - ten feet from any adjoining or adjacent buildings, HVAC intakes, or supply registers.
- Rain caps, if used, should be installed to decrease the potential for extracted subsurface vapors to enter the building.
- To avoid accidental changes to the system that could disrupt its function, the depressurization system should be labeled clearly.
- A warning device or indicator should be installed to alert building occupants if the active system stops working properly. Examples of system failure warning devices and indicators include the following: a liquid gauge (e.g., a manometer), a sound alarm, a light indicator, and a dial (needle display) gauge. The warning device or indicator should be placed where it can be easily heard or seen. The party installing the system should verify the warning device or indicator is working properly. Building occupants should be made aware of the warning device or indicator (what it is, where it is located, how it works, how to read/understand it, and what to do if it indicates the system is not working properly).
- An electric meter that records the operating time should be installed so that it provides an easy means of documenting the time the system was in operation

d) *HVAC systems* — HVAC systems should be carefully designed, installed, and operated to avoid depressurization of basements and other areas in contact with the soil.

e) *Crawl space ventilation* —
- Ventilation systems should be designed to avoid the creation of other health, safety, or environmental hazards to building occupants (e.g., back drafting of natural draft combustion appliances).
- Openings and cracks in floors above the crawl space that would permit air to pass into or out of the occupied spaces of the building, should be identified, closed and sealed.

f) *SVE systems designed to also mitigate exposures* –
   - The systems should be designed to avoid the creation of other health, safety, or environmental hazards to building occupants (e.g., back drafting of natural draft combustion appliances).
   - To avoid reentry of soil vapor into the building(s), the exhaust point should be located away from the openings of buildings and HVAC air intakes. Depending upon the concentrations of volatile chemicals in subsurface vapors and the expected mass removal rate, treatment (e.g., via carbon filters) of the SVE system effluent may be appropriate to minimize outdoor air effects.
   - The SVE system's radius of influence should adequately address buildings requiring mitigation, as well as subsurface sources requiring remediation. If it does not, additional actions may be appropriate. For example, if the radius of influence does not completely extend beneath a building, a complementary air monitoring program may be appropriate to confirm that exposures are being addressed adequately while the SVE system is operating.

4.2.3 Technical Guidance

To address exposures effectively in larger buildings, some of the same techniques used in residential buildings can be scaled up in size, number, or performance (e.g., adjustments in the size and air movement capacity of the vent pipe fan, or installation of multiple suction points through the slab instead of a single point). The design of the techniques may also be modified (e.g., installation of horizontal pipes beneath the building instead of a single suction point).

Detailed technical guidance on designing and installing mitigation systems in residential and non-residential buildings is provided in various documents, such as the following, released by the U.S. EPA and others:

a) References provided in ASTM's E-2121 and the U.S. EPA's *Model Standards and Techniques for Control of Radon in New Residential Buildings*.
b) *Radon Reduction Techniques for Existing Detached Houses: Technical Guidance (Third Edition) for Active Soil Depressurization Systems* U.S. EPA [U.S. EPA 625/R-93-011, October 1993]. This technical guidance document has been prepared to serve as a comprehensive aid in the detailed selection, design, installation, and operation of indoor radon reduction measures for existing houses based on active soil depressurization techniques. It is intended for use by radon mitigation contractors, building contractors, concerned homeowners, state and local officials, and other interested persons. Copies can be ordered from the U.S. EPA's Indoor Air Quality Information Clearinghouse at 1-800-438-4318.
c) *Protecting Your Home from Radon: A Step-by-Step Manual for Radon Reduction.* Kladder *et al.*, 1993. This manual is designed to provide sufficient information to a homeowner to make many of the basic repairs that can significantly reduce radon levels in the home.

d) *Building Radon Out: A Step-by-Step Guide on How to Build Radon-Resistant Homes.* U.S. EPA [U.S EPA 402-K-01-002, April 2001]. This fully illustrated guide contains all the information needed in one place to educate home builders about radon-resistant new construction, including the following: basic questions and detailed answers about radon and radon-resistant new construction, specific planning steps before installing a system, detailed installation instructions with helpful illustrations, tips and tricks when installing a system, marketing know-how when dealing with homebuyers, and architectural drawings. This document is available at the U.S. EPA's web site: http://www.epa.gov/iaq/radon/pubs/index.html.
e) *Radon Prevention in the Design and Construction of Schools and Other Large Buildings.* U.S. EPA [U.S. EPA 625-R-92-016, June 1994]. It is typically easier and much less expensive to design and construct a new building with radon-resistant and/or easy-to-mitigate features, than to add these features after the building is completed and occupied. Specific guidelines on how to incorporate radon prevention features in the design, construction of schools, and other large buildings are detailed in this manual. Copies can be ordered from the U.S. EPA's Indoor Air Quality Information Clearinghouse at 1-800-438-4318. This document is also available on the U.S. EPA Office of Research and Development's web site: www.epa.gov/ORD/NRMRL/pubs/625r92016/625r92016.htm.

4.3 Post-Mitigation or Confirmation Testing

Once a mitigation system is installed, its effectiveness and proper installation should be confirmed. The party that installed the system should develop a post-mitigation testing plan and conduct post-mitigation testing. Minimum objectives for post-mitigation testing associated with specific mitigation methods are provided in the following subsections. All post-mitigation testing activities should be documented.

4.3.1 Sub-slab Depressurization System with Sealing

a) Reasonable and practical actions should be taken to identify and fix leaks. With the depressurization system operating, smoke tubes are used to check for leaks through concrete cracks, floor joints, and at the suction point. Any leaks identified should be resealed until smoke is no longer observed flowing through the opening.
b) Once a depressurization system is installed, its operation may compete with the proper venting of fireplaces, wood stoves and other combustion or vented appliances (e.g., furnaces, clothes dryers, and water heaters), resulting in the accumulation of exhaust gases in the building and the potential for carbon monoxide poisoning. Therefore, in buildings with natural draft combustion appliances, the building should be tested for back drafting of the appliances. Back drafting conditions should be corrected before the depressurization system is placed in operation.
c) The distance that a pressure change is induced in the sub-slab area (i.e., a pressure field extension test) should be tested. Analogous to a communication test, this test is commonly conducted by operating the depressurization system and simultaneously

observing the movement of smoke downward into small holes (e.g., 3/8 inch), drilled through the slab at sufficient locations to demonstrate that a vacuum is being created beneath the entire slab. A similar quantitative evaluation may also be performed by using a digital micromanometer or comparable instrument. If adequate depressurization is not occurring, the reason (e.g., improper fan operation) should be identified and corrected.

d) The extent of the pressure change must cover the entire extent of the structure, and it must be confirmed through monitoring points placed in each of the farthest corners/extent of the structure. In very limited circumstances (large manufacturing facilities), the source of the vapors can be confirmed to be present in a smaller footprint than the entire foundation area (through soil, soil gas, sub-slab vapor, and groundwater sampling). It may be possible to limit the extent of the mitigation as long as it can be demonstrated that all of the vapors that are migrating from a source are controlled.

e) Prior to initiating the verification monitoring program, the sub-slab depressurization system must be able to continuously operate. During the start-up of the system the installer should conduct leak testing, verify that there is no back drafting condition occurring, conduct an initial pressure field extension test, and verify that all of the warning devices and meters are operational.

f) Demonstrating that the negative pressure is being maintained is an important part of any mitigation system. Table 4.1 outlines an example of the verification monitoring that may be conducted to demonstrate that the negative pressure beneath the slab is being maintained.

Table 4.1 **System Verification Readings**

All readings should be consecutive and the length of time between readings should not extend longer than the monitoring period.

Frequency	***Notes/Comments***
Initiation	Consecutive readings collected over a ten hour period
Daily	Reading collected at least once a day, for four days (time lines may be continued after a weekend).
Weekly	Record readings once per week. A minimum of four day consecutive readings demonstrating a negative pressure must be recorded prior to proceeding to the next step. Weather conditions must be included in the documentation.
Monthly*	Record readings once per month. A minimum of three consecutive readings demonstrating a negative pressure must be recorded prior to proceeding to the next step. Considerations should be made to document different weather conditions throughout the month.
Quarterly*	Record readings once per month. A minimum of three consecutive quarterly demonstrating a negative pressure must be recorded prior to proceeding to the next step. Considerations should be made to document different weather conditions throughout each quarter.
Yearly*	Yearly system checks and verification should be maintained.

** Additional daily monitoring periods should be included in the weekly, monthly, quarterly, and yearly events to document the systems effectiveness during different weather events and extremes*

g) Adequate operation of the warning device or indicator should be confirmed on a monthly basis, in addition to recording the meter readings that demonstrate the system was operating over the specified time period.
h) If necessary, post-mitigation indoor and outdoor air sampling should be conducted in all buildings where pre-mitigation samples were collected and in all buildings where physical data suggest possible impediments to comprehensive sub-slab communication of the depressurization system (i.e., locations with wet or dense sub-slab soils, multiple foundations and footings, minimal pressure differentials between the interior and sub-slab). Generally, indoor and outdoor air sampling locations, protocols, and analytical methods should be consistent between pre-mitigation and post-mitigation sampling, where applicable. In buildings with basements, post-mitigation indoor air sampling from the basement alone (i.e., without a concurrent indoor air sample from the first floor) is recommended in most circumstances. Indoor air samples should be collected consistent with the description in Section 2.7.3.

Typically, post-mitigation sampling should be conducted no sooner than 30 days after installing a depressurization system. If the system is installed outside of the heating season or at the end of a season, post-mitigation air sampling may be postponed until the heating season. If post-mitigation sampling results do not indicate a significant decrease in the concentrations of volatile chemicals previously believed to be present in the indoor air due to soil vapor intrusion, the reason (e.g., indoor or outdoor sources, improper operation of the mitigation system) should be identified and corrected as appropriate.

4.3.2 Sub-membrane Depressurization System with Soil Vapor Retarder

a) Items in 4.3.1 should be considered for testing and verification.
b) Reasonable and practical actions should be taken to identify and fix leaks. With the depressurization system operating, smoke tubes are used to check for leaks in the membrane at seams, edge seals and at locations where the sheet was sealed around obstructions. Any leaks identified should be resealed until smoke is no longer observed flowing through the opening.
c) Back drafting conditions should be evaluated and corrected [Section 4.3.1].
d) Adequate operation of the warning device or indicator should be confirmed.
e) Post-mitigation indoor and outdoor air testing should be conducted in buildings where pre-mitigation samples were collected [as discussed in Section 4.3.1].

4.3.3 HVAC Modifications

a) Positive pressure conditions for the building should be verified (e.g., verify a pressure controller is maintaining the desired pressure differential and/or measure the pressure differential between the sub-slab and indoor air by using field instruments).
b) Back drafting conditions should be evaluated and corrected [Section 4.3.1].

c) Adequate operation of the warning device or indicator, if applicable, should be confirmed.
d) Post-mitigation indoor and outdoor air testing should be conducted in buildings where pre-mitigation samples were collected [Section 4.3.1].

4.3.4 Crawl Space Ventilation and Sealing

a) Reasonable and practical actions should be taken to identify and fix leaks. With the ventilation system operating, smoke tubes are used to check for leaks in openings and cracks in floors above the crawl space that were sealed during installation of the system. Any leaks identified should be resealed until smoke is no longer observed flowing through the opening.
b) Back drafting conditions should be evaluated and corrected [Section 4.3.1].
c) Adequate operation of the warning device or indicator, if applicable, should be confirmed.
d) Post-mitigation indoor and outdoor air testing should be conducted in buildings where pre-mitigation samples were collected [as discussed in Section 4.3.1].

4.3.5 SVE Systems Designed to Also Mitigate Exposures

Back drafting conditions should be evaluated and corrected [Section 4.3.1]. The distance that a pressure change is induced in the sub-slab area should be conducted. This may be done by operating the SVE system and simultaneously observing the movement of smoke downward into small holes (e.g., 3/8 inch) drilled through the building's slab at sufficient locations to demonstrate that a vacuum is being created beneath the entire slab. Adequate operation of the warning device or indicator, if applicable, should be confirmed. Post-mitigation indoor and outdoor air testing should be conducted in buildings where pre-mitigation samples were collected [Section 4.3.1].

4.4 Operation, Maintenance, and Monitoring of Mitigation Systems

When mitigation systems are implemented at a site, the OM&M protocols for the systems should be included in a site-specific site management plan. The party that installed the system must conduct OM&M activities and should develop the site management plan.

Recommendations for minimum OM&M activities associated with specific mitigation methods are provided in the following subsections. Also included is a discussion of non-routine maintenance. All routine and non-routine OM&M activities should be documented and reported to the MDEQ.

4.4.1 Sub-slab Depressurization Systems and Sub-Membrane Depressurization Systems

Routine maintenance should commence within 18 months after the system becomes operational, and should occur every 12 to 18 months thereafter.

During routine maintenance, the following activities (at a minimum) should be conducted:

a) A visual inspection of the complete system (e.g., vent fan, piping, warning device or indicator, labeling on systems, soil vapor retarder integrity).
b) Identification and repair of leaks [Sections 4.3.1 and 4.3.2].
c) Inspection of the exhaust or discharge point to verify no air intakes have been located nearby.

As appropriate, preventative maintenance (e.g., replacing vent fans), repairs and/or adjustments should be made to the system to ensure its continued effectiveness at mitigating exposures related to soil vapor intrusion. The need for preventative maintenance will depend upon the life expectancy and warranty for the specific part, as well as visual observations over time. The need for repairs and/or adjustments will depend upon the results of a specific activity compared to that obtained when system operations were initiated.

If significant changes are made to the system or when the system's performance is unacceptable, the system may need to be redesigned and restarted. Many, if not all, of the post-mitigation testing activities, as described in Section 4.3, may be appropriate. The extent of such activities will primarily depend upon the reason for the changes and the documentation of sub-slab depressurization.

Generally, air monitoring is not recommended if the system has been installed properly and is maintaining a vacuum beneath the entire slab.

In addition to the routine OM&M activities described here, the building's owner and tenants must be given information packages that explain the system's operation, maintenance, and monitoring. These information packages should be kept updated and provided to any prospective purchaser, new owners, or tenant.

4.4.2 Other Mitigation Systems

For other mitigation systems (e.g., HVAC modifications, crawl space ventilation), routine maintenance activities are generally comparable to post-mitigation testing activities [Section 4.3]. Activities typically include a visual inspection of the complete system, and identification and repair of leaks. System performance checks, such as air stream velocity measurements of ventilation systems, also should be performed.

As appropriate, preventative maintenance (e.g., replacing filters, cleaning lines), repairs and/or adjustments should be made to the system to ensure its continued effectiveness at mitigating exposures related to soil vapor intrusion. If significant changes are made to the system or when the system's performance is unacceptable, redesigning and restarting the system may be appropriate [Section 4.4.1].

Air monitoring, such as periodic sub-slab vapor, indoor air, and outdoor air sampling, may be appropriate to determine whether existing building conditions are maintaining the desired

mitigation endpoint and to determine whether changes are appropriate. The type and frequency of monitoring is determined based upon site-specific and building-specific conditions, taking into account applicable environmental data, building operating conditions, and the mitigation method employed.

4.4.3 Non-routine Maintenance

Non-routine maintenance may also be appropriate during the operation of a mitigation system. Examples of such situations include the following:

a) The building's owners or occupants report that the warning device or indicator indicates the mitigation system is not operating properly;
b) The building's owner or occupants change;
c) The mitigation system becomes damaged; or
d) The building has undergone renovations that may reduce the effectiveness of the mitigation system.

Activities conducted during non-routine maintenance visits will vary depending upon the reason for the visit. In general, building-related activities may include examining the building for structural or HVAC system changes, or other changes that may affect the performance of the depressurization system (e.g., new combustion appliances, deterioration of the concrete slab, or significant changes to any of the building factors listed in Table 1.2). Depressurization system-related activities may include examining the operation of the warning device or indicator and the vent fan, or the extent of sub-slab depressurization. Repairs or adjustments should be made to the system as appropriate. If appropriate, the system should be redesigned and restarted [Section 4.4.1].

4.5 Termination of Mitigation System Operations

Systems should remain in place and operational until they are no longer needed to address current or potential exposures related to soil vapor intrusion. This determination should be based upon several factors, including the following:

a) Subsurface sources (e.g., groundwater, soil) of volatile chemical contamination in subsurface vapors have been remediated based upon an evaluation of appropriate post-remedial sampling results.
b) Residual contamination, if any, in subsurface vapors is not expected to affect indoor air quality significantly based upon soil vapor and/or sub-slab vapor sampling results.
c) Residual contamination, if any, in subsurface vapors is not affecting indoor air quality when active mitigation systems are turned off based upon indoor air, outdoor air, and sub-slab vapor sampling results at a representative number of buildings.

d) There is no observed "rebound" effect for which additional mitigation efforts would be appropriate when the mitigation system is turned off for prolonged periods of time. This determination should be based upon multiple sampling events of indoor air, outdoor air and/or sub-slab vapor sampling from the building over a time period, determined by site-specific conditions.

Given the prevalence of radon, consideration should be given to leaving the system in place and operating to address exposures related to radon intrusion after concurrence is reached that the system is no longer needed to mitigate exposures related to soil vapor intrusion. This action must be done only with permission of the property owner and after the property owner is aware of their responsibilities in operating, monitoring, and maintaining the system for this specific purpose. If the property owner declines the offer, the system should be shut down and, if requested, removed in a timely manner.

4.6 Michigan Air Pollution Control Rules

Mitigation systems under Michigan is Part 55, Air Pollution Control rules are identified as a point source discharge. Therefore the installation of an active vapor mitigation system would need to either apply for a permit (in accordance with the Part 55 Rules), or be able to complete the necessary documentation to show that the installed system would qualify for a permit exemption. Though a permit may not be necessary in many circumstances, the sampling to demonstrate that a site can maintain its exemption often requires the same sampling and documentation as if a permit was required. Rule 290 grants an exemption from the permit if the applicant can continually demonstrate that the uncontrolled VOC emissions from a system are less than the threshold level of 1,000 pounds per month of non-carcinogens and 20 pounds per month of most carcinogens. At Part 201 and Part 213 facilities, this would require (in most circumstances) that each structure (or point source), that is a part of a facility and that has a mitigation system; must maintain, collect, and model the data to show that an exemption is applicable. The documentation for the exemption must also include: 1) a description of the emission unit is maintained throughout the life of the unit; 2) records of material use and calculations identifying the quality, nature, and quantity of the air contaminant emissions are maintained in sufficient detail to demonstrate that the emissions meet the emission limits outlined in the rule; and 3) the records are maintained on file for the most recent two-year period and are made available upon request to the MDEQ.

Sampling to demonstrate compliance should include samples collected and modeled from each discharge point. Though the Air Quality Division or the RRD does not need to approve the exemption, enough detail must be provided upon request in the Section 7a Compliance Analysis to demonstrate that the exemption is applicable. This requires multiple sampling events. All air sampling conducted must be collected and analyzed by TO-15 or another approved method (Op Memo No. 2).

5. REFERENCES

Berry-Spark, K., T. McAlary, and N. Bice. 2004. Empirical Alpha Factors at "Wet Basement" Sites EPA/AEHS, Vapor Intrusion Attenuation Workshop, Day 1, San Diego, CA, March 15, 2004.

Hartman, B. 2003. "How to Collect Reliable Soil-Gas Data for Upward Risk Assessments, Part 2: Surface Flux-Chamber Method," *LUSTLine Bulletin 44:14-18, 34, August 2003*

Hayes, H. 2008. "The Impact of Sample Media on Soil Gas Measurements," presented at CA DTSC Soil Gas Advisory Forums, March 4, 2008 & March 14, 2008

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.

Johnson, P. C. 2002. Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model. American Petroleum Institute, Technical Bulletin No. 17. May 2002.

Johnson, P. C and L. Deize-Abreu. 2003. Confusion? Delusion? What Do We Really Know About Vapor Intrusion. Groundwater Resources Association Symposium on Groundwater Contaminants; Subsurface Vapor Intrusion to Indoor Air: When Is Soil and Groundwater Contamination an Indoor Air Issue? September 30, 2003 (San Jose) and October 1, 2003 (Long Beach)

Laubacher, R. C., P. Bartholomae, P. Velasco, and H. J. Reisinger. 1997. An Evaluation of the Vapor Profile in the Vadose Zone above a Gasoline Plume. Pages 396-409 *in* The Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection and Remediation Conference, Houston, TX.

Lowell, P.S., and Eklund, B. 2004. "VOC Emission Fluxes as a Function of Lateral Distance from the Source." Environmental Progress, Vol. 23, No.1, April 2004. pp. 52-58.

McAlary, T. 2003. "Conceptual Models of Vapor Intrusion," GeoSyntec Consultants, Inc., Presentation for USEPA Seminar on Indoor Air Vapor Intrusion, February 25-26, 2003, Session 2.

Oswald, Taylor, 1988. Track Etch Radon Detectors for Long-Term Radon Measurement, Radon and the Environment Published By William J. Makofske, Michael R. Edelstein

Rehwagen, M., U. Schlink, and O. Herbarth. 2003. Seasonal cycle of VOCs in apartments. Indoor Air 13:283-291.

Tillman, Fred D, and James W. Weaver. 2005, Review of Recent Research on Vapor Intrusion, U.S. Environmental Protection Agency, Washington DC, EPA/600/R-05/106.

Tuday, M. 2008. "Observations and Practical Observations and Practical Experience in Soil Gas Analysis Experience in Soil Gas Analysis from a Laboratory Perspective," presented at CA DTSC Soil Gas Advisory Forums, March 4, 2008 & March 14, 2008

Weaver, James W., and Fred D Tillman. 2005, Uncertainty and the Johnson-Ettinger Model for Vapor Intrusion Calculations, U.S. Environmental Protection Agency, Washington DC, EPA/600/R-05/110.

ASTM is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. ASTM standards referenced in this document include:

- ASTM E2121-03. - Standard Practice for Installing Radon Mitigation Systems in Existing Low-rise Residential Buildings
- ASTM E96/E96M-05. Standard Test Methods for Water Vapor Transmission of Materials.
- ASTM D412-06a. Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers-Tension.
- ASTM D543-06. Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents
- ASTM D1434-82. Standard Test Method for Determining Gas Permeability Characteristics of Plastic Film and Sheeting
- ASTM E 1745-97. "Standard Specification for Plastic Water Vapor Retarders Used in Contact with Soil or Granular Fill under Concrete Slabs".

All ASTM Standards are available at: www.astm.org

A partial list of available Guidance Documents the MDEQ has reviewed and evaluated as part of developing this guidance document:

American Petroleum Institute (API). 2005. Collecting and Interpreting Soil Gas Samples from the Vadose Zone A Practical Strategy for Assessing the Subsurface Vapor-to-Indoor Air Migration Pathway at Petroleum Hydrocarbon Sites) Publication No. 4741. Washington D.C.

Colorado Department of Public Health and Environment. 2004. Indoor Air Guidance, Colorado Department of Public Health and Environment, Hazardous Materials and Waste Management Division, Draft, September 2004.

Department of Toxic Substances Control California Environmental Protection Agency, 2004. Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Revised February 7, 2005

New Jersey Department of Environmental Protection. 2005. Vapor Intrusion Guidance

New York State Department of Health. 2006. "Guidance for Evaluating Soil Vapor Intrusion in the State of New York", Final, October, 2006.

U.S. Environmental Protection Agency (USEPA). 2002. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Draft Subsurface Vapor Intrusion Guidance). Office of Solid Waste and Emergency Response, Washington, DC. USEPA530-F-02-052

U.S. Environmental Protection Agency (USEPA). 2008. "U.S. EPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors – Draft," Office of Solid Waste and Emergency Response, Washington, DC. March 4, 2008

Dominic, D. 2007. "Sub-Slab Probe Installation," U.S. Environmental Protection Agency Office of Research and Development National Risk Management Research Laboratory Ground Water and Ecosystems Restoration Submitted to AWMA's Specialty Conference on Vapor Intrusion: Learning form the Challenges, Sept 26-28, 2007, Providence, RI

Appendix A: Decision Matrix for Determining Appropriate and Acceptable Sampling Strategies for Assessment of Indoor Air Risk

PROGRAM PURPOSE / SAMPLING TECHNIQUE AND GUIDANCE (Shading – Indicates guidance is available)	INITIAL ASSESSMENT	INTERIM RESPONSE DECISIONS		DUE CARE	REMEDIAL DECISIONS
	FACILITY DETERMINATION / CHARACTERIZATION TO DETERMINE EXTENT OF CONTAMINATION ABOVE GENERIC CRITERIA	SAFETY ASSESSMENT	CURRENT EXPOSURES REQUIRING ACTION	7A COMPLIANCE ANALYSIS DOCUMENTATION OF COMPLIANCE (Rule 1003(5))	REMEDIAL ACTION PLANS CORRECTIVE ACTION PLANS LONG TERM MONITORING
INDOOR AIR SAMPLING GUIDANCE FOR COLLECTION AND ANALYSIS OF INDOOR AIR SAMPLES; PART 201/213 ACCEPTABLE INDOOR AIR CONCENTRATIONS	NA	√		√ (a), (b)	NA
SOIL GAS SAMPLING GUIDANCE FOR COLLECTION AND ANALYSIS OF SOIL GAS SAMPLES	Generally NA (e)	√		√ (a), (c)	Generally NA (d)
GROUNDWATER SAMPLING SAMPLING STRATEGIES AND STATISTICS TRAINING MATERIALS FOR PART 201 CLEANUP CRITERIA (GUIDESHEETS 4, 5, 14 AND 22)	√	√		√	√
SOIL SAMPLING SAMPLING STRATEGIES AND STATISTICS TRAINING MATERIALS FOR PART 201 CLEANUP CRITERIA (GUIDESHEETS 4, 5, 14 AND 22)	√	√		√	√

NA – The sampling technique and guidance is not applicable.
(a) – Due Care obligation is triggered from an exceedance of promulgated generic soil or groundwater criteria, not from indoor air sampling results that exceed acceptable indoor air concentrations or soil gas sampling results that exceed soil gas screening concentrations.
(b) – Due Care compliance may be demonstrated by representative indoor air sampling that documents:

- There is no current unacceptable exposure that requires mitigation.
- Confirms exposure has been mitigated with the implementation of other control measures (e.g., HVAC).

(c) – Due Care compliance may be demonstrated by representative soil gas sampling that documents there is no current unacceptable exposure that requires mitigation.
(d) – Appropriate only for limited category RAPs/CAPs where land or resource use restrictions address the indoor air pathway through construction restrictions.
(e) – Appropriate only for methane, which is the only substance at this time with a soil gas criterion

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

AIACs are concentrations in building indoor air that are protective of occupant exposures assumed for the appropriate generic land use category. The AIACs were generated as a necessary starting point for back-calculating the Part 201 Groundwater and Soil Volatilization to Indoor Air Inhalation Criteria and the Part 213 Groundwater and Soil Volatilization to Indoor Air Risk-Based Screening Levels. *These concentrations are not provided to suggest that indoor air sampling is appropriate or necessary for assessing indoor air pathway risk for all sites. See footnote "a" for further explanation of issues related to indoor air sampling.* Concentrations are in units of ug/m3 and ppbv. See footnote "b" for an explanation of how ppbv is calculated. When calculating the acceptable soil gas screening concentrations (ASGSCs) for soil gas at a depth of five feet or greater, the AIAC is divided by the attenuation coefficient of 0.002 for all volatile organic compounds (VOCs). To obtain the ASGSCs for shallow soil gas, an attenuation coefficient of 0.02 is applied for all VOCs. The ASGSC are based on the higher of the health-based soil gas screening values and the soil gas analytical reporting limits.

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Acenaphthene	83329	219	3.5E+1	313	5.0E+1	1.1E+5	1.7E+4	1.1E+4	1.7E+3	1.6E+5	2.5E+4	1.6E+4	2.5E+3
Acenaphthylene	208968	37	5.9E+0	52	8.4E+0	1.9E+4	3.0E+3	1.9E+3	3.0E+2	2.6E+4	4.2E+3	2.6E+3	4.2E+2
Acetaldehyde	75070	9.4	5.2E+0	13	7.2E+0	4.7E+3	2.6E+3	4.7E+2	2.6E+2	6.5E+3	3.6E+3	6.5E+2	3.6E+2
Acetate	71501	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Acetic acid	64197	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Acetone	67641	6,150	2.6E+3	8,800	3.7E+3	3.1E+6	1.3E+6	3.1E+5	1.3E+5	4.4E+6	1.9E+6	4.4E+5	1.9E+5
Acetonitrile	75058	63	3.8E+1	89	5.3E+1	3.2E+4	1.9E+4	3.2E+3	1.9E+3	4.5E+4	2.7E+4	4.5E+3	2.7E+3
Acetophenone	98862	511	1.0E+2	730	1.5E+2	2.6E+5	5.2E+4	2.6E+4	5.2E+3	3.7E+5	7.4E+4	3.7E+4	7.4E+3
Acrolein	107028	0.021	9.2E-3	0.030	1.3E-2	1.1E+1	4.6E+0	1.1E+0	4.6E-1	1.5E+1	6.5E+0	1.5E+0	6.5E-1
Acrylamide	79061	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Acrylic acid	79107	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Acrylonitrile	107131	0.36	1.7E-1	1.5	6.9E-1	1.8E+2	8.3E+1	1.8E+1	8.3E+0	7.5E+2	3.5E+2	7.5E+1	3.5E+1
Alachlor	15972608	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Aldicarb	116063	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Aldicarb sulfoxide	1646873	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Aldicarb sulfone	1646884	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Aldrin	309002	0.0050	3.4E-4	0.020	1.3E-3	2.5E+0	1.7E-1	2.5E-1	1.7E-2	1.0E+1	6.7E-1	1.0E+0	6.7E-2
Aluminum	7429905	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Ammonia	7664417	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
t-Amyl methyl ether (TAME)	994058	65	1.6E+1	92	2.2E+1	3.3E+4	7.8E+3	3.3E+3	7.8E+2	4.6E+4	1.1E+4	4.6E+3	1.1E+3
Aniline	62533	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Anthracene	120127	1,040	1.4E+2	1,490	2.0E+2	5.2E+5	7.1E+4	5.2E+4	7.1E+3	7.5E+5	1.0E+5	7.5E+4	1.0E+4
Antimony	7440360	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Arsenic	7440382	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Asbestos	1332214	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Atrazine	1912249	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Azobenzene	103333	0.78	1.0E-1	3.2	4.3E-1	3.9E+2	5.2E+1	3.9E+1	5.2E+0	1.6E+3	2.1E+2	1.6E+2	2.1E+1
Barium	7440393	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzene	71432	2.9	9.1E-1	12	3.8E+0	1.5E+3	4.5E+2	1.5E+2	4.5E+1	6.0E+3	1.9E+3	6.0E+2	1.9E+2
Benzidine	92875	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzo(a)anthracene	56553	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzo(b)fluoranthene	205992	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Benzo(k)fluoranthene	207089	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzo(g,h,i)perylene	191242	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzo(a)pyrene	50328	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Benzoic acid	65850	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzyl alcohol	100516	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Benzyl chloride	100447	0.49	9.5E-2	2.0	3.9E-1	2.5E+2	4.7E+1	2.5E+1	4.7E+0	1.0E+3	1.9E+2	1.0E+2	1.9E+1
Beryllium	7440417	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
bis(2-Chloroethoxy)ethane	112265	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
bis(2-Chloroethyl)ether	111444	0.074	1.3E-2	0.30	5.1E-2	3.7E+1	6.3E+0	3.7E+0	6.3E-1	1.5E+2	2.6E+1	1.5E+1	2.6E+0
bis(2-Ethylhexyl)phthalate	117817	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Boron	7440428	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Bromate	15541454	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Bromobenzene	108861	8.34	1.3E+0	12	1.9E+0	4.2E+3	6.5E+2	4.2E+2	6.5E+1	6.0E+3	9.3E+2	6.0E+2	9.3E+1
Bromodichloromethane	75274	0.66	9.9E-2	2.7	4.0E-1	3.3E+2	4.9E+1	3.3E+1	4.9E+0	1.4E+3	2.0E+2	1.4E+2	2.0E+1
Bromoform	75252	22	2.1E+0	90	8.7E+0	1.1E+4	1.1E+3	1.1E+3	1.1E+2	4.5E+4	4.4E+3	4.5E+3	4.4E+2
Bromomethane	74839	5.2	1.3E+0	7.5	1.9E+0	2.6E+3	6.7E+2	2.6E+2	6.7E+1	3.8E+3	9.7E+2	3.8E+2	9.7E+1
n-Butanol	71363	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2-Butanone (MEK)	78933	1,040	3.5E+2	1,490	5.1E+2	5.2E+5	1.8E+5	5.2E+4	1.8E+4	7.5E+5	2.5E+5	7.5E+4	2.5E+4
n-Butyl acetate	123864	7,400	1.6E+3	1,060	2.2E+2	3.7E+6	7.8E+5	3.7E+5	7.8E+4	5.3E+5	1.1E+5	5.3E+4	1.1E+4
t-Butyl alcohol	75650	1,970	6.5E+2	2,800	9.2E+2	9.9E+5	3.3E+5	9.9E+4	3.3E+4	1.4E+6	4.6E+5	1.4E+5	4.6E+4
Butyl benzyl phthalate	85687	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
n-Butylbenzene	104518	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
sec-Butylbenzene	135988	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
tert-Butylbenzene	98066	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Cadmium	7440439	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Camphene	79925	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Caprolactam	105602	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Carbaryl	63252	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Carbazole	86748	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Carbofuran	1563662	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Carbon disulfide	75150	730	2.3E+2	1,000	3.2E+2	3.7E+5	1.2E+5	3.7E+4	1.2E+4	5.0E+5	1.6E+5	5.0E+4	1.6E+4
Carbon tetrachloride	56235	1.0	1.6E-1	4.2	6.7E-1	5.0E+2	7.9E+1	5.0E+1	7.9E+0	2.1E+3	3.3E+2	2.1E+2	3.3E+1
Chlordane	57749	0.24	1.4E-2	0.99	5.9E-2	1.2E+2	7.2E+0	1.2E+1	7.2E-1	5.0E+2	3.0E+1	5.0E+1	3.0E+0
Chloride	16887006	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Chlorobenzene	108907	73	1.6E+1	100	2.2E+1	3.7E+4	7.9E+3	3.7E+3	7.9E+2	5.0E+4	1.1E+4	5.0E+3	1.1E+3
para-Chlorobenzenesulfonic acid	98668	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
1-chloro-1,1-difluoroethane	75683	52100	1.3E+4	74500	1.8E+4	2.6E+7	6.3E+6	2.6E+6	6.3E+5	3.7E+7	9.1E+6	3.7E+6	9.1E+5
Chloroethane	75003	10,000	3.8E+3	15,000	5.7E+3	5.0E+6	1.9E+6	5.0E+5	1.9E+5	7.5E+6	2.8E+6	7.5E+5	2.8E+5
2-Chloroethyl vinyl ether	110758	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Chloroform	67663	10	2.0E+0	41	8.4E+0	5.0E+3	1.0E+3	5.0E+2	1.0E+2	2.1E+4	4.2E+3	2.1E+3	4.2E+2
Chloromethane	74873	38	1.8E+1	134	6.5E+1	1.9E+4	9.2E+3	1.9E+3	9.2E+2	6.7E+4	3.2E+4	6.7E+3	3.2E+3
4-Chloro-3-methylphenol	59507	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
beta-Chloronaphthalene	91587	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
2-Chlorophenol	95578	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
o-Chlorotoluene	95498	73	1.4E+1	104	2.0E+1	3.7E+4	7.1E+3	3.7E+3	7.1E+2	5.2E+4	1.0E+4	5.2E+3	1.0E+3

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Chlorpyrifos	2921882	2.1	1.5E-1	3.0	2.1E-1	1.1E+3	7.3E+1	1.1E+2	7.3E+0	1.5E+3	1.0E+2	1.5E+2	1.0E+1
Chromium (III)	16065831	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Chromium (VI)	18540299	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Chrysene	218019	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Cobalt	7440484	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Copper	7440508	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Cyanazine	21725462	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Cyanide	57125	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Cyclohexanone	108941	1,000	2.5E+2	1,500	3.7E+2	5.0E+5	1.2E+5	5.0E+4	1.2E+4	7.5E+5	1.9E+5	7.5E+4	1.9E+4
Dacthal	1861321	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dalapon	75990	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
4-4'-DDD	72548	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
4-4'-DDE	72559	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
4-4'-DDT	50293	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Decabromodiphenyl ether	1163195	37	9.4E-1	52	1.3E+0	1.9E+4	4.7E+2	1.9E+3	4.7E+1	2.6E+4	6.6E+2	2.6E+3	6.6E+1
Di-n-butyl phthalate	84742	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Di(2-ethylhexyl) adipate	103231	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Di-n-octyl phthalate	117840	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diacetone alcohol	123422	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diazinon	333415	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dibenzo(a,h)anthracene	53703	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dibenzofuran	132649	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Dibromochloromethane	124481	0.99	1.2E-1	4.1	4.8E-1	5.0E+2	5.8E+1	5.0E+1	5.8E+0	2.1E+3	2.4E+2	2.1E+2	2.4E+1
Dibromochloropropane	96128	0.21	2.2E-2	0.30	3.1E-2	1.1E+2	1.1E+1	1.1E+1	1.1E+0	1.5E+2	1.6E+1	1.5E+1	1.6E+0
Dibromomethane	74953	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Dicamba	1918009	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,2-Dichlorobenzene	95501	1,600	2.7E+2	2,200	3.7E+2	8.0E+5	1.3E+5	8.0E+4	1.3E+4	1.1E+6	1.8E+5	1.1E+5	1.8E+4
1,3-Dichlorobenzene	541731	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
1,4-Dichlorobenzene	106467	3.5	5.8E-1	14	2.3E+0	1.8E+3	2.9E+2	1.8E+2	2.9E+1	7.0E+3	1.2E+3	7.0E+2	1.2E+2
3,3'-Dichlorobenzidine	91941	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dichlorodifluoromethane	75718	52,000	1.1E+4	74,000	1.5E+4	2.6E+7	5.3E+6	2.6E+6	5.3E+5	3.7E+7	7.5E+6	3.7E+6	7.5E+5
1,1-Dichloroethane	75343	520	1.3E+2	750	1.9E+2	2.6E+5	6.4E+4	2.6E+4	6.4E+3	3.8E+5	9.3E+4	3.8E+4	9.3E+3
1,2-Dichloroethane	107062	0.94	2.3E-1	3.8	9.4E-1	4.7E+2	1.2E+2	4.7E+1	1.2E+1	1.9E+3	4.7E+2	1.9E+2	4.7E+1
1,1-Dichloroethylene	75354	0.49	1.2E-1	2.0	5.0E-1	2.5E+2	6.2E+1	2.5E+1	6.2E+0	1.0E+3	2.5E+2	1.0E+2	2.5E+1
cis-1,2-Dichloroethylene	156592	36	9.1E+0	51	1.3E+1	1.8E+4	4.5E+3	1.8E+3	4.5E+2	2.6E+4	6.4E+3	2.6E+3	6.4E+2
trans-1,2-Dichloroethylene	156605	73	1.8E+1	100	2.5E+1	3.7E+4	9.2E+3	3.7E+3	9.2E+2	5.0E+4	1.3E+4	5.0E+3	1.3E+3
2,6-Dichloro-4-nitroaniline	99309	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,4-Dichlorophenol	120832	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,4-Dichlorophenoxyacetic acid	94757	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,2-Dichloropropane	78875	4.2	9.1E-1	6.0	1.3E+0	2.1E+3	4.5E+2	2.1E+2	4.5E+1	3.0E+3	6.5E+2	3.0E+2	6.5E+1
1,3-Dichloropropene	542756	6.1	1.3E+0	25	5.5E+0	3.1E+3	6.7E+2	3.1E+2	6.7E+1	1.3E+4	2.8E+3	1.3E+3	2.8E+2
Dichlorovos	62737	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Dicyclohexyl phthalate	84617	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Dieldrin	60571	0.0053	3.4E-4	0.022	1.4E-3	2.7E+0	1.7E-1	2.7E-1	1.7E-2	1.1E+1	7.1E-1	1.1E+0	7.1E-2
Diethyl ether	60297	13,000	4.3E+3	18,000	5.9E+3	6.5E+6	2.1E+6	6.5E+5	2.1E+5	9.0E+6	3.0E+6	9.0E+5	3.0E+5
Diethyl phthalate	84662	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diethylene glycol monobutyl ether	112345	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diisopropyl ether	108203	370	8.9E+1	530	1.3E+2	1.9E+5	4.4E+4	1.9E+4	4.4E+3	2.7E+5	6.3E+4	2.7E+4	6.3E+3
Diisopropylamine	108189	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Dimethyl phthalate	131113	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
N,N-Dimethylacetamide	127195	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
N,N-Dimethylaniline	121697	2.1	4.2E-1	8.4	1.7E+0	1.1E+3	2.1E+2	1.1E+2	2.1E+1	4.2E+3	8.5E+2	4.2E+2	8.5E+1
Dimethylformamide	68122	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,4-Dimethylphenol	105679	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,6-Dimethylphenol	576261	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
3,4-Dimethylphenol	95658	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dimethylsulfoxide	67685	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,4-Dinitrotoluene	121142	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Dinoseb	88857	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,4-Dioxane	123911	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diquat	85007	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Diuron	330541	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Endosulfan	115297	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Endothall	145733	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Endrin	72208	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Epichlorohydrin	106898	1.0	2.6E-1	1.5	4.0E-1	5.0E+2	1.3E+2	5.0E+1	1.3E+1	7.5E+2	2.0E+2	7.5E+1	2.0E+1
Ethanol	64175	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Ethyl acetate	141786	3,300	9.2E+2	4,770	1.3E+3	1.7E+6	4.6E+5	1.7E+5	4.6E+4	2.4E+6	6.6E+5	2.4E+5	6.6E+4
Ethyl tertiary butyl ether (ETBE)	637923	390	9.3E+1	556	1.3E+2	2.0E+5	4.7E+4	2.0E+4	4.7E+3	2.8E+5	6.7E+4	2.8E+4	6.7E+3
Ethylbenzene	100414	79	1.8E+1	320	7.4E+1	4.0E+4	9.1E+3	4.0E+3	9.1E+2	1.6E+5	3.7E+4	1.6E+4	3.7E+3
Ethylene dibromide	106934	0.11	1.4E-2	0.45	5.9E-2	5.5E+1	7.2E+0	5.5E+0	7.2E-1	2.3E+2	2.9E+1	2.3E+1	2.9E+0
Ethylene glycol	107211	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Ethylene glycol monobutyl ether	111762	14,000	2.9E+3	19,400	4.0E+3	7.0E+6	1.4E+6	7.0E+5	1.4E+5	9.7E+6	2.0E+6	9.7E+5	2.0E+5
Fluoranthene	206440	150	1.8E+1	209	2.5E+1	7.5E+4	9.1E+3	7.5E+3	9.1E+2	1.0E+5	1.3E+4	1.0E+4	1.3E+3
Fluorene	86737	150	2.2E+1	209	3.1E+1	7.5E+4	1.1E+4	7.5E+3	1.1E+3	1.0E+5	1.5E+4	1.0E+4	1.5E+3
Fluorine (soluble fluoride)	7782414	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Formaldehyde	50000	1.9	1.5E+0	7.6	6.2E+0	9.5E+2	7.7E+2	9.5E+1	7.7E+1	3.8E+3	3.1E+3	3.8E+2	3.1E+2
Formic acid	64186	2.09	1.1E+0	2.98	1.6E+0	2.1E+0	1.1E+0	1.0E+2	5.6E+1	1.5E+3	7.9E+2	1.5E+2	7.9E+1
1-Formylpiperidine	2591868	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Gentian violet	548629	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Glyphosate	1071836	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Heptachlor	76448	0.019	1.2E-3	0.076	5.0E-3	9.5E+0	6.2E-1	9.5E-1	6.2E-2	3.8E+1	2.5E+0	3.8E+0	2.5E-1
Heptachlor epoxide	1024573	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
n-Heptane	142825	3,700	9.0E+2	5,210	1.3E+3	1.9E+6	4.5E+5	1.9E+5	4.5E+4	2.6E+6	6.4E+5	2.6E+5	6.4E+4

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Hexabromobenzene	87821	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Hexachlorobenzene (C-66)	118741	0.053	4.6E-3	0.22	1.9E-2	2.7E+1	2.3E+0	2.7E+0	2.3E-1	1.1E+2	9.4E+0	1.1E+1	9.4E-1
Hexachlorobutadiene (C-46)	87683	1.1	1.0E-1	4.5	4.2E-1	5.5E+2	5.2E+1	5.5E+1	5.2E+0	2.3E+3	2.1E+2	2.3E+2	2.1E+1
alpha-Hexachlorocyclohexane	319846	0.013	1.1E-3	0.054	4.5E-3	6.5E+0	5.5E-1	6.5E-1	5.5E-2	2.7E+1	2.3E+0	2.7E+0	2.3E-1
beta-Hexachlorocyclohexane	319857	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Hexachlorocyclopentadiene (C-56)	77474	0.21	1.9E-2	0.30	2.7E-2	1.1E+2	9.4E+0	1.1E+1	9.4E-1	1.5E+2	1.3E+1	1.5E+1	1.3E+0
Hexachloroethane	67721	3.7	3.8E-1	5.2	5.4E-1	1.9E+3	1.9E+2	1.9E+2	1.9E+1	2.6E+3	2.7E+2	2.6E+2	2.7E+1
n-Hexane	110543	210	6.0E+1	298	8.5E+1	1.1E+5	3.0E+4	1.1E+4	3.0E+3	1.5E+5	4.2E+4	1.5E+4	4.2E+3
2-Hexanone	591786	42	1.0E+1	60	1.5E+1	2.1E+4	5.1E+3	2.1E+3	5.1E+2	3.0E+4	7.3E+3	3.0E+3	7.3E+2
Indeno(1,2,3-cd)pyrene	193395	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Iron	7439896	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Isobutyl alcohol	78831	1,600	5.3E+2	2,200	7.3E+2	8.0E+5	2.6E+5	8.0E+4	2.6E+4	1.1E+6	3.6E+5	1.1E+5	3.6E+4
Isophorone	78591	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Isopropyl alcohol	67630	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Isopropyl benzene	98828	91	1.8E+1	130	2.6E+1	4.6E+4	9.1E+3	4.6E+3	9.1E+2	6.5E+4	1.3E+4	6.5E+3	1.3E+3
Lead	7439921	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Lindane	58899	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Lithium	7439932	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Magnesium	7439954	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Manganese	7439965	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Mercury (Elemental)	7439976	0.31	3.8E-2	0.45	5.5E-2	1.6E+2	1.9E+1	1.6E+1	1.9E+0	2.3E+2	2.7E+1	2.3E+1	2.7E+0
Methane	74828	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Methanol	67561	3,400	2.6E+3	4,800	3.7E+3	1.7E+6	1.3E+6	1.7E+5	1.3E+5	2.4E+6	1.8E+6	2.4E+5	1.8E+5
Methoxychlor	72435	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
2-Methoxyethanol	109864	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2-Methyl-4-chlorophenoxyacetic acid	94746	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2-Methyl-4,6-dinitrophenol	534521	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
N-Methyl-morpholine	109024	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Methyl parathion	298000	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
4-Methyl-2-pentanone (MIBK)	108101	2,100	5.1E+2	3,050	7.4E+2	1.1E+6	2.6E+5	1.1E+5	2.6E+4	1.5E+6	3.7E+5	1.5E+5	3.7E+4
Methyl-tert-butyl ether (MTBE)	1634044	3,100	8.6E+2	4,470	1.2E+3	1.6E+6	4.3E+5	1.6E+5	4.3E+4	2.2E+6	6.2E+5	2.2E+5	6.2E+4
Methylcyclopentane	96377	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
4,4'-Methylene-bis-2-chloroaniline (MBOCA)	101144	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Methylene chloride	75092	52	2.5E+1	210	1.0E+2	2.6E+4	1.3E+4	2.6E+3	1.3E+3	1.1E+5	5.1E+4	1.1E+4	5.1E+3
2-Methylnaphthalene	91576	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Methylphenols	1319773	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Metolachlor	51218452	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Metribuzin	21087649	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Mirex	2385855	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Molybdenum	7439987	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Naphthalene	91203	3.1	5.9E-1	4.5	8.6E-1	1.6E+3	3.0E+2	1.6E+2	3.0E+1	2.3E+3	4.3E+2	2.3E+2	4.3E+1
Nickel	7440020	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
Nitrate	14797558	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Nitrite	14797650	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Nitrobenzene	98953	0.73	1.5E-1	1.0	2.0E-1	3.7E+2	7.3E+1	3.7E+1	7.3E+0	5.0E+2	9.9E+1	5.0E+1	9.9E+0
2-Nitrophenol	88755	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
n-Nitroso-di-n-propylamine	621647	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
N-Nitrosodiphenylamine	86306	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Oxamyl	23135220	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Oxo-hexyl acetate	88230357	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Pendimethalin	40487421	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Pentachlorobenzene	608935	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Pentachloronitrobenzene	82688	5.2	4.3E-1	7.5	6.2E-1	2.6E+3	2.2E+2	2.6E+2	2.2E+1	3.8E+3	3.1E+2	3.8E+2	3.1E+1
Pentachlorophenol	87865	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Pentane	109660	19,000	6.4E+3	26,800	9.1E+3	9.5E+6	3.2E+6	9.5E+5	3.2E+5	1.3E+7	4.5E+6	1.3E+6	4.5E+5
2-Pentene	109682	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Phenanthrene	85018	0.10	1.4E-2	0.15	2.1E-2	5.0E+1	6.9E+0	5.0E+0	6.9E-1	7.5E+1	1.0E+1	7.5E+0	1.0E+0
Phenol	108952	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Phosphorus (total)	7723140	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Phthalic acid	88993	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Phthalic anhydride	85449	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Picloram	1918021	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Piperidine	110894	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Polybrominated biphenyls	67774327	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Polychlorinated biphenyls (PCBs)	1336363	0.041	3.7E-3	0.17	1.5E-2	2.1E+1	1.9E+0	2.1E+0	1.9E-1	8.5E+1	7.7E+0	8.5E+0	7.7E-1
Prometon	1610180	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Propachlor	1918167	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Propazine	139402	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Propionic acid	79094	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Propyl alcohol	71238	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
n-Propylbenzene	103651	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Propylene glycol	57556	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Pyrene	129000	100	1.2E+1	149	1.8E+1	5.0E+4	6.0E+3	5.0E+3	6.0E+2	7.5E+4	9.0E+3	7.5E+3	9.0E+2
Pyridine	110861	3.7	1.1E+0	5.2	1.6E+0	1.9E+3	5.7E+2	1.9E+2	5.7E+1	2.6E+3	8.0E+2	2.6E+2	8.0E+1
Selenium	7782492	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Silver	7440224	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Silvex (2,4,5-TP)	93721	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Simazine	122349	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Sodium	7440235	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Sodium azide	26628228	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Strontium	7440246	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Styrene	100425	43	1.0E+1	170	4.0E+1	2.2E+4	5.1E+3	2.2E+3	5.1E+2	8.5E+4	2.0E+4	8.5E+3	2.0E+3
Sulfate	14808798	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Tebuthiuron	34014181	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV

APPENDIX B: Parts 201 and 213 Acceptable Indoor Air Concentrations (AIACs)[a] and Acceptable Soil Gas Screening Concentrations (ASGSCs)

Hazardous Substance	Chemical Abstract Service Number	Residential Acceptable Indoor Air Concentration		Industrial and Commercial II, III and IV Acceptable Indoor Air Concentration		DEEP 5' Residential Acceptable Soil Gas Screening Concentration		SUB-SLAB Residential Acceptable Soil Gas Screening Concentration		DEEP 5' Industrial Acceptable Soil Gas Screening Concentration		SUB-SLAB Industrial Acceptable Soil Gas Screening Concentration	
		(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)	(µg/m^3)	(ppbv)
2,3,7,8-Tetrabromodibenzo-p-dioxin	50585416	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,2,4,5-Tetrachlorobenzene	95943	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746016	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,1,1,2-Trichloroethane	630206	3.3	4.8E-1	13	1.9E+0	1.7E+3	2.4E+2	1.7E+2	2.4E+1	6.5E+3	9.5E+2	6.5E+2	9.5E+1
1,1,2,2-Tetrachloroethane	79345	0.42	6.1E-2	1.7	2.5E-1	2.1E+2	3.1E+1	2.1E+1	3.1E+0	8.5E+2	1.2E+2	8.5E+1	1.2E+1
Tetrachloroethylene	127184	42	6.2E+0	170	2.5E+1	2.1E+4	3.1E+3	2.1E+3	3.1E+2	8.5E+4	1.3E+4	8.5E+3	1.3E+3
Tetrahydrofuran	109999	6,200	2.1E+3	8,790	3.0E+3	3.1E+6	1.1E+6	3.1E+5	1.1E+5	4.4E+6	1.5E+6	4.4E+5	1.5E+5
Tetranitromethane	509148	0.0016	2.0E-4	0.0066	8.2E-4	8.0E-1	1.0E-1	8.0E-2	1.0E-2	3.3E+0	4.1E-1	3.3E-1	4.1E-2
Thallium	7440280	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Toluene	108883	420	1.1E+2	600	1.6E+2	2.1E+5	5.6E+4	2.1E+4	5.6E+3	3.0E+5	8.0E+4	3.0E+4	8.0E+3
p-Toluidine	106490	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Toxaphene	8001352	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Triallate	2303175	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
Tributylamine	102829	7.3	9.6E-1	10	1.3E+0	3.7E+3	4.8E+2	3.7E+2	4.8E+1	5.0E+3	6.6E+2	5.0E+2	6.6E+1
1,2,4-Trichlorobenzene	120821	390	5.3E+1	550	7.4E+1	2.0E+5	2.6E+4	2.0E+4	2.6E+3	2.8E+5	3.7E+4	2.8E+4	3.7E+3
1,1,1-Trichloroethane	71556	1,000	1.8E+2	1,490	2.7E+2	5.0E+5	9.2E+4	5.0E+4	9.2E+3	7.5E+5	1.4E+5	7.5E+4	1.4E+4
1,1,2-Trichloroethane	79005	1.5	2.8E-1	6.2	1.1E+0	7.5E+2	1.4E+2	7.5E+1	1.4E+1	3.1E+3	5.7E+2	3.1E+2	5.7E+1
Trichloroethylene	79016	14	2.6E+0	58	1.1E+1	7.0E+3	1.3E+3	7.0E+2	1.3E+2	2.9E+4	5.4E+3	2.9E+3	5.4E+2
Trichlorofluoromethane	75694	59,000	1.1E+4	83,700	1.5E+4	3.0E+7	5.3E+6	3.0E+6	5.3E+5	4.2E+7	7.5E+6	4.2E+6	7.5E+5
2,4,5-Trichlorophenol	95954	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
2,4,6-Trichlorophenol	88062	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
1,2,3-Trichloropropane	96184	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
1,1,2-Trichloro-1,2,2-trifluoroethane	76131	80,000	1.0E+4	114,000	1.5E+4	4.0E+7	5.2E+6	4.0E+6	5.2E+5	5.7E+7	7.4E+6	5.7E+6	7.4E+5
Triethanolamine	102716	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Triethylene glycol	112276	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
3-Trifluoromethyl-4-nitrophenol	88302	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Trifluralin	1582098	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
2,2,4-Trimethyl pentane	540841	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
2,4,4-Trimethyl-2-pentene	107404	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID	ID
1,2,4-Trimethylbenzene	95636	1,300	2.6E+2	1,830	3.7E+2	6.5E+5	1.3E+5	6.5E+4	1.3E+4	9.2E+5	1.9E+5	9.2E+4	1.9E+4
1,3,5-Trimethylbenzene	108678	1,300	2.6E+2	1,830	3.7E+2	6.5E+5	1.3E+5	6.5E+4	1.3E+4	9.2E+5	1.9E+5	9.2E+4	1.9E+4
Triphenyl phosphate	115866	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
tris(2,3-Dibromopropyl)phosphate	126727	0.046	1.6E-3	0.19	6.7E-3	2.3E+1	8.1E-1	2.3E+0	8.1E-2	9.5E+1	3.3E+0	9.5E+0	3.3E-1
Urea	57136	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Vanadium	7440622	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Vinyl acetate	108054	210	6.0E+1	298	8.5E+1	1.1E+5	3.0E+4	1.1E+4	3.0E+3	1.5E+5	4.2E+4	1.5E+4	4.2E+3
Vinyl chloride	75014	5.5	2.2E+0	23	9.0E+0	2.8E+3	1.1E+3	2.8E+2	1.1E+2	1.2E+4	4.5E+3	1.2E+3	4.5E+2
White phosphorus	12185103	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV
Xylenes	1330207	4,600	1.1E+3	6,560	1.5E+3	2.3E+6	5.3E+5	2.3E+5	5.3E+4	3.3E+6	7.6E+5	3.3E+5	7.6E+4
Zinc	7440666	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV	NLV

APPENDIX C

Standard Operating Procedures
for
Vapor Intrusion Applications

Section I
Indoor Air Sampling
Via
Compendium Method TO-15

Section II
Vapor Monitoring Wells and Implants
Sub-slab Vapor Monitoring Point

Section I

Indoor Air Sampling
Via
Compendium Method TO-15

The information contained in this Standard Operating Procedure (SOP) is drawn from existing manuals, various reference documents, and a broad range of colleagues with considerable practical and educational backgrounds. This SOP outlines the generic procedures necessary to install a soil gas probe, vapor monitoring point, or Sub-slab vapor implant. Site conditions, contaminants, and geology may require modifications of this procedure.

Table of Contents

Section I

1. INDOOR AIR SAMPLING **4**

2. SAMPLING PROCEDURES IN THE STRUCTURE **4**

3. SAMPLE COLLECTION **5**

3.1 SAMPLE HOLD TIME 5
3.2 ASSOCIATED HARDWARE 6
3.2.1 Valve *6*
3.2.2 Brass Cap *6*
3.2.3 Particulate Filter *6*
3.2.4 Fittings *6*
3.2.5 Vacuum Gauge *7*
3.2.6 Flow Controllers *7*
3.3 FINAL CANISTER VACUUM AND FLOW CONTROLLER PERFORMANCE 7
3.4 CONSIDERATIONS FOR SAMPLING WITH CANISTERS 8
3.5 STEP-BY-STEP PROCEDURES FOR INTEGRATED SAMPLING 9

4. REFERENCES **11**

Section II

1. SOIL GAS PROBE AND VAPOR MONITORING POINT **23**

1.1. SOIL GAS PROBE MATERIALS AND CONSTRUCTION 23
1.2. PROBE INSTALLATION PROTOCOL 23

2. SUB-SLAB MONITORING POINT **28**

2.1 SUB-SLAB MONITORING POINT MATERIALS AND CONSTRUCTION 28
2.2 SUB-SLAB MONITORING POINT INSTALLATION PROTOCOL 30

3. SAMPLE COLLECTION **33**

4. QUALITY ASSURANCE AND QUALITY CONTROL SAMPLES **36**

5. FIELD RECORDS **36**

6. REFERENCES **39**

1. Indoor Air Sampling

Indoor air samples must be analyzed in accordance with Remediation and Redevelopment Division (RRD) Operational Memorandum (Op Memo) No. 2, Attachment 3, Indoor Air Designated Methods and Target Detection Limits. Alternate analysis methods, as described in the U.S. EPA document, "*Compendium of Methods for the Determination of Air Pollutants in Indoor Air*," may be proposed for the Michigan Department of Environmental Quality (MDEQ) approval. In determining what method to use, laboratory detection limits must be compared from each method to the Acceptable Indoor Air Concentrations (AIAC) to assure that the detection limits will be equal to or less than the corresponding generic AIACs.

This SOP is applicable to analysis of air samples collected in specially prepared stainless steel canisters. Canisters included are SUMMA® polished interior canisters and SilcoSteel® silica coated interior canisters. It focuses on collecting an indoor air sample utilizing an inert canister to collect a "whole air sample" in which the compounds remain in the gas matrix, which is then analyzed by Compendium Method TO-15 (U.S. EPA, 1999). Other methods are possible (as outlined in RRD Op Memo No. 2, Attachment 3); however, TO-15 should be considered for use when a subset of the 97 Title III Volatile Organic Compounds (VOCs) constitute the target list. Use of other approved air methods will require the sampling collection to be modified accordingly.

Canisters are prepared for sampling by evacuating the contents to a vacuum of approximately 29.9 inches of Mercury (in. Hg). Opening the stainless steel bellows valve allows the air sample to enter the canister. When the correct volume of sample is collected, the valve is closed and the canister is returned for analysis (Hayes, 2007).

2. Sampling Procedures in the Structure

Prior to the actual collection of an indoor air sample, an inspection of the structure must be conducted and an occupant survey completed to adequately identify the presence of, or occupant activities that could generate, any possible indoor air emission sources of target VOCs. The Indoor Air Resident Survey at the end of this SOP is an example of the inspection form that must be filled out when conducting indoor air sampling. All potential sources of VOCs inside the building must be documented by completion of an occupied dwelling questionnaire. All sources identified in the questionnaire must be removed, eliminated, and shut off if possible at least 24 hours prior to initiation of the sampling event (see also the Instructions for Occupants for Indoor Air Sampling Events at the end of this appendix). If any source cannot be removed, the additional steps taken to minimize its potential effects must be documented.

An adequate number of indoor air sampling events, including at least one during the heating season, are required to be representative of the indoor air contaminant concentrations under the different meteorological and building operational conditions that occur throughout the year. The required number of sampling events should be determined on a case-by-case basis and may vary across a facility.

Sample collection duration should reflect the exposure scenario being evaluated without compromising the detection limit or sample collection flow rate (e.g., an eight hour sample from a workplace with a single shift versus a 24 hour sample for a residential unit to assess occupant exposures (U.S. EPA, 2002). The structure must be closed (windows and doors shut) for two to 24 hours before sampling begins (longer times equate to better data), and the use of appliances that induce large pressure differences (e.g., furnaces, wood stoves, air conditioning systems, exhaust fans, clothes dryers, operating fireplaces) must be avoided during this time. The greater the sampling duration, the more reliable the results are for estimating exposures.

NOTE
Alternate sample collection methods may be proposed to confirm the effectiveness of active mitigation systems.

Samples must be collected from the basement and each floor of the building. Specific locations within each floor should be biased towards areas of high activity such as family rooms, kitchen or dining areas, or areas at commercial or industrial buildings where workers spend the majority of their time. Minimum sample frequencies are one sample per 250 square feet (ft^2) for residential, and one per 1,000 ft^2 for commercial or industrial. Sampling devices should not be placed near doors, windows, stairways, or air supplies. Samples must be collected from the normal breathing zone (two to five feet above the floor), near the center of the room and at least one foot from any object. One duplicate sample is required per ten samples minimum, or per structure, in each sample round, preferably from the lowest or basement level. For basements, one sample must be placed near the floor wall seam or sump, and one sample as near as possible to the center of the basement space. Multiple unit residential structures (e.g., duplexes and condominiums) require special sampling considerations. Sampling strategies for these structures must be discussed with the MDEQ project manager.

Concurrent ambient air (outdoor) samples must be collected from at least two locations upwind of each structure; one within the horizontal boundary of the contaminant area (preferably near the building), and one outside of the contaminant boundary. One field and/or trip blank must be included in each sampling event.

3. Sample Collection

3.1 Sample Hold Time

The hold time is very compound-specific. For example, compounds such as chloroform, benzene, and vinyl chloride are typically stable in a canister for at least 30 days. The U.S. EPA Method TO-15 states, “Fortunately, under conditions of normal usage for sampling ambient air, most VOCs may be recovered from canisters near their original concentrations for after storage times of up to thirty days.” However, some VOCs degrade quickly and demonstrate low recovery even after seven days (Hayes, 2007). The MDEQ recommends a maximum of 14 days for most compounds; however, identification of all the contaminants of concern (COCs) at a site should be provided to the laboratory to determine if a shorter holding time is necessary.

3.2 Associated Hardware

Associated hardware used with the canister includes the valve, brass cap, particulate filter, and vacuum gauge.

3.2.1 Valve

A 1/4 inch stainless steel bellows valve (manufactured by Swagelok or Parker Instruments) should be mounted at the top of the canister. The valve allows vacuum to be maintained in the canister prior to sampling and seals off the canister once the sample has been collected. No more than a half turn by hand is required to open the valve. Do not over tighten the valve after sampling or it may become damaged. A damaged valve can leak, possibly compromising the sample. Some canisters have a metal cage near the top to protect the valve (Hayes, 2007).

3.2.2 Brass Cap

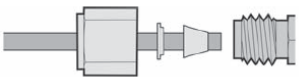
Each canister comes with a brass cap (i.e., Swagelok 1/4 inch plug) secured to the inlet of the valve assembly. The cap serves two purposes: first, it ensures that there is no loss of vacuum due to a leaky valve or a valve that is accidentally opened during handling; second, it prevents dust and other particulate matter from fouling the valve. The cap is removed prior to sampling and replaced following sample collection (Hayes, 2007).

3.2.3 Particulate Filter

Particulate filters may be used when sampling with a canister. A separate filter should be used for each sample collection to prevent any cross-contamination (Hayes, 2007).

(Provided by Hayes, 2007)

3.2.4 Fittings



(Provided by Hayes, 2007)

Standard hardware fittings are 1/4 inch Swagelok; a 9/16 inch wrench is used to assemble the hardware. Compression fittings should be used for all connections; never use tube-in-tube connections. It is critical to avoid leaks in the sampling train. Leaks of ambient air through fittings between pieces of the sampling train (e.g., tubing to particulate filter) will dilute the sample and cause the canister to fill at a faster rate than desired (Hayes, 2007).

3.2.5 Vacuum Gauge

(Provided by Hayes, 2007)

A vacuum gauge is used to measure the initial vacuum of the canister before sampling and the final vacuum upon completion. A gauge can also be used to monitor the fill rate of the canister; however, most gauges should be considered as only a rough estimate of the pressure and should only be used to obtain a relative measure of "change" (Hayes, 2007).

3.2.6 Flow Controllers

An air sample collected over time is referred to as an integrated sample and can provide information on compound concentrations in air averaged or composited over time. Illustrated below are some of the most common hardware configurations used to take an integrated sample. Flow controllers are devices that regulate the flow of air during sampling into an evacuated canister. Also known as flow restrictors, these devices enable a sampler to achieve a desired flow rate and thus, a sampling interval. The flow controller should allow the sample to be collected equally over a set period of time (Hayes, 2007).

(Provided by Hayes, 2007)

3.3 Final Canister Vacuum and Flow Controller Performance

The final vacuum of a 6 liter (L) canister should be between 5 and 10 in. Hg. As long as the differential pressure is greater than 4 in. Hg ambient pressure, the flow through the device will remain approximately constant as the canister fills. If there is insufficient differential pressure, the flow through the controller will decrease as the canister pressure approaches ambient. Because of the normal fluctuations in the flow rate (due to changes in ambient temperature, pressure, and diaphragm instabilities) during sampling, the final vacuum will range between 2 and 10 in. Hg. General considerations of the final canister vacuum include:

- If the residual canister vacuum is greater than 5 in. Hg (i.e., more vacuum), less than 5 L of sample was collected in a 6 L canister. When the canister is pressurized to five pounds per square inch prior to analysis, sample dilution will be greater than normal. This will result in elevated reporting limits.

- If the residual canister vacuum is less than 5 in. Hg (i.e., less vacuum), the initial flow rate was high or there was a leak in the connection. Once the vacuum decreases below 5 in. Hg, the flow rate begins to drop significantly. This scenario indicates that the sample is skewed in favor of the first portion of the sampling interval.

- If the final vacuum is near ambient (i.e., less than 1 in. Hg), there is inadequate differential pressure to drive the flow controller. The sampler cannot be certain the desired sampling interval was achieved before the canister arrived at ambient conditions. Although the actual sampling interval is uncertain, the canister still contains a sample from the site.

Table 3.1 identifies the relationship between the final canister vacuum and the dilution factor which may affect the ability of the sample to hit required detection limits (Hayes, 2007).

Table 3.1: Relationship between Final Canister Vacuum, Volume Sampled, and Dilution Factor of a 6L Canister

Final Vacuum (In. Hg)	0	2.5	5	7.5	10	12.5	15	17.5	20
Volume Sampled (L)	6	5.5	5.4	5	4	3.5	3	2.5	2
Dilution Factor*	1.34	1.46	1.61	1.79	2.01	2.30	2.68	3.22	4.02

* Canister pressurized to 5 psig for analysis

$$\text{Final Reporting Limit} = \text{Method Reporting Limit} \times \text{Dilution Factor}_{\text{(Canister Pressurization)}} \times \text{Dilution Factor}_{\text{(Sample Concentration)}}$$

$$\text{Dilution Factor}_{\text{(Canister Pressurization)}} = \frac{\text{Pressurization for Analysis}}{\text{Receipt Vacuum}} = \frac{14.7\ \text{psig} + \text{Press. for Analysis (psig)}}{14.7\ \text{psig}\left[1 - \frac{\text{Rec. Vac (In Hg)}}{29.9\ \text{In. Hg}}\right]}$$

(Provided by Hayes, 2007)

3.4 Considerations for Sampling with Canisters

Avoid Leaks in the Sampling Train: A leak in any connection will mean that some air will be pulled in through the leak and not through the flow controller. A final pressure reading near ambient is one indication that there may have been a leak.

Verify Initial Vacuum of Canister: See Section 3.5 for detailed instructions on verifying initial canister vacuum.

Monitor Integrated Sampling Progress: It's a good idea to monitor the progress of the sampling during the sampling interval. The volume of air sampled is a linear function of the canister vacuum. For example, halfway (four hours) into an eight-hour sampling interval, the canister should be half filled (2.5 L), and the gauge should read approximately 17 in. Hg. More vacuum than 17 in. Hg indicates that the canister is filling too slowly; less than 17 in. Hg and the canister is filling too quickly. If the canister is filling too slowly, a valid sample can still be collected (see Section 3.2.4). If the canister is filling too quickly because of a leak or incorrect flow controller setting, corrective action can be taken. Ensuring all connections are tight may eliminate a leak. It is possible to take an intermittent sample.

Avoid Contamination: Flow controllers should be cleaned between uses. This is done by returning them to the laboratory.

Caution against Sampling in Extreme Temperatures: There can be some flow rate drift if the temperature of the controllers is allowed to vary significantly.

3.5 Step-by-Step Procedures for Integrated Sampling

These procedures are for a typical ambient air sampling application; actual field conditions and procedures may vary.

Before Arriving at the Field

1. Verify contents of the shipped package (e.g., chain-of-custody, canister, particulate filter and flow controller).
2. Verify the gauge is working properly.
3. Verify the initial vacuum of the canister.

It is important to check the vacuum of the canister prior to use. The initial vacuum of the canister should be greater than 25 in. Hg. If the canister vacuum is less than 25 in. Hg, do not use it.

Vacuum Verification

The procedure to verify the initial vacuum of a canister is simple but unforgiving:

1. Confirm the valve is closed (knob should already be tightened clockwise).
2. Remove the brass cap.

3. Attach gauge.
4. Attach brass cap to side of gauge tee fitting, if one is not already there, to ensure a closed train.
5. Open and close valve quickly (a few seconds).
6. Read vacuum on the gauge.
7. Record gauge reading on “Initial Vacuum” column of chain-of-custody.
8. Verify the canister valve is closed and remove gauge.
9. Replace the brass cap.

Sample Collection

1. Confirm the valve is closed (knob should already be tightened clockwise).
2. Remove brass cap from canister.
3. Attach flow controller to canister.
4. Place the brass cap at the end of the flow controller creating an air tight train, and quickly open and close the canister valve in order to check for leaks. If the needle on the gauge drops, your train is not airtight. In this case, try refitting your connections and/or tightening them until the needle holds steady.
5. Once the sample train is airtight, remove the brass cap from the flow controller and open the canister valve, one-half turn.
6. Monitor integrated sampling progress periodically.
7. Verify and record final vacuum of canister (simply read built-in gauge).
8. Close valve by hand tightening knob clockwise.
9. Replace brass cap.
10. Fill out canister sample tag (make sure the sample ID and date of collection recorded on the sample tag matches what is recorded on the COC exactly).
11. Return canisters in boxes provided.
12. Return sample media in packaging provided.
13. Fill out chain-of-custody and relinquish samples properly (it is important to note the canister serial numbers on the chain-of-custody).
14. Place chain-of-custody in box and retain copy.
15. Tape box shut and affix custody seal at each opening (if applicable).
16. Ship accordingly to meet method holding times.

The final vacuum of a 6L canister should be between 5 and10 in. Hg and the final vacuum should be noted on the chain-of-custody. This will enable the laboratory to compare the final vacuum with the receipt vacuum (i.e., the vacuum measured upon arrival at the laboratory).

Important Information for Canister Sampling

- DO NOT use a canister to collect explosive substances, radiological or biological agents, corrosives, extremely toxic substances or other hazardous materials. It is illegal to ship such substances.
- ALWAYS use a filter when sampling.
- NEVER allow liquids (including water) or corrosive vapors to enter canister.
- DO NOT attach labels to the surface of the canister or write on the canister.
- DO NOT over tighten the valve and remember to replace the brass cap.

4. References

Hayes, H. (2007). Canister and Bag Sampling Guide. *Air Toxics Ltd. Publication, Revision 5,* March 2007, http://www.airtoxics.com/literature/AirToxicsLtdSamplingGuide.pdf

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). 2002. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Draft Subsurface Vapor Intrusion Guidance). Office of Solid Waste and Emergency Response, Washington, DC. USEPA530-F-02-052

Instructions for Occupants

INDOOR AIR SAMPLING EVENTS

_____will be collecting one or more indoor air samples from your building in the near future. In order to collect an indoor air sample in your structure that is both representative of indoor conditions and avoids the common sources of background air contamination associated with household activities and consumer products, your assistance is requested.

Please follow the instructions below starting at least 48 hours prior to and during the indoor air sampling event:

- Operate your furnace and whole house air conditioner as appropriate for the current weather conditions.
- Do not use wood stoves, fireplaces or auxiliary heating equipment.
- Do not open windows or keep doors open.
- Avoid using window air conditioners, fans or vents.
- Do not smoke in the building.
- Do not use air fresheners or odor eliminators.
- Do not use paints or varnishes (up to a week in advance, if possible).
- Do not use cleaning products (e.g., bathroom cleaners, furniture polish, appliance cleaners, all-purpose cleaners, floor cleaners).
- Do not use cosmetics, including hair spray, nail polish remover, perfume, etc.
- Avoid bringing freshly dry cleaned clothes into the building.
- Do not partake in hobbies indoors that use solvents.
- Do not apply pesticides.
- Do not store containers of gasoline, oil or petroleum based or other solvents within the building or attached garages (except for fuel oil tanks).
- Do not operate or store automobiles in an attached garage.
- Do not operate gasoline powered equipment within the building, attached garage or around the immediate perimeter of the building.

You will be asked a series of questions about the structure, consumer produces you store in your building, and household activities typically occurring in the building. These questions are designed to help us differentiate chemical vapors from your household products from those related to subsurface contamination. Additionally, the analyte list may include only a select few target analytes and not a “wide variety of chemicals”. Various compounds found in common household products (such as paint, new carpeting, nail polish remover), might be found in your sample results.

Your cooperation is greatly appreciated. If you have any questions about these instructions, please feel free to contact:_____

_____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM

Date: _____ Survey Performed by: _____

1. OCCUPANT:

Rent: _____ Own: _____

Resident Name: _____

Address: _____

Telephone: Home: _____ Work: _____

How long have you lived at this location? _____

List current occupants/occupation below (attach additional page if necessary):

Age (If under 18)	Sex (M/F)	Occupation

2. OWNER OR LANDLORD: (If same as occupant, check here ___ and go to Item No. 3)

Last Name: _____ First Name: _____

Address: _____

City and State: _____

County: _____

Home Phone:_____ Office Phone: _____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

3. SENSITIVE POPULATION:

Daycare/Nursing Home/ Hospital/School/Other (specify): _____

4. BUILDING CHARACTERISTICS:

Residential/Multi-family Residential/Office/Strip Mall/Commercial/Industrial/School

Describe Building: _____ Year Constructed: _____

Number of floors at or above grade: _____

Number of floors below grade: _____ (full basement/crawl space/slab on grade)

Depth of structure below grade: _____ ft. Basement size: _____ ft^2

If the property is residential, what type? (Circle all appropriate responses.)

Ranch	2-Family	3-Family	Raised Ranch
Split Level	Colonial	Cape Cod	Contemporary
Mobile Home	Duplex	Apartment House	Townhouses/Condos
Modular	Log Home	Other: _____	

If multiple units, how many? _____

If the property is commercial:

Business type(s) _____

Does it include residences (i.e., multi-use)? Yes No If yes, how many? _____

5. OCCUPANCY:

Is basement/lowest level occupied? (Circle one)

Full-time Occasionally Seldom Almost Never

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

Level	**General Use** **(e.g., family room, bedroom, laundry, workshop, storage)**
Basement	_____
1st Floor	_____
2nd Floor	_____
3rd Floor	_____
4th Floor	_____

(Use additional page(s) as necessary)

6. CONSTRUCTION CHARACTERISTICS: (Circle all that apply.)

a. Above Grade Construction: (Describe, e.g.: wood frame, concrete, stone, brick.)

_____

b. Basement Type: Full Crawlspace Slab Other: _____

c. Basement Floor: Concrete Dirt Stone Other: _____

d. Finished Basement Floor: Uncovered Covered

If covered, what with? _____

e. Foundation Walls: Poured Block Stone Other: _____

f. Foundation Walls: Unsealed Sealed Sealed with: _____

g. The Basement is: Wet Damp Dry

h. The Basement is: Finished Unfinished Partially Finished

i. Sump Present (Y / N) If yes, how many? _____

Where Discharged? _____

Water in Sump? Yes No Not Applicable

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

Identify all potential soil vapor entry points and estimated size (e.g., cracks, utility parts, drains).

_____

_____

_____

_____

Are the basement walls or floor sealed with waterproof paint or epoxy coatings? Yes No

Type of ground cover outside of building: Grass Concrete Asphalt Other _____

Is an existing subsurface depressurization (radon) system in place? Yes No

If yes, is it active, or passive?

Is a sub-slab vapor/moisture barrier in place? Yes No

Type of barrier: _____

7. HEATING, VENTING, and AIR CONDITIONING

Type of heating system(s) used in this building: (Circle all that apply: Note the primary.)

Hot Air Circulation	Heat Pump	Hot Water Baseboard
Space Heaters	Steam Radiation	Radiant Floor
Electric Baseboard	Wood Stove	Outdoor Wood Boiler

Other: _____

The primary type of fuel used is:

Natural Gas	Fuel Oil	Kerosene
Electric	Propane	Solar
Wood	Coal	

Domestic hot water tank fueled by: _____

Location of Boiler/Furnace: Basement Outdoors Main Floor Other _____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

Air Conditioning: Central Air Window Units Open Windows None

Are air distribution ducts present? Yes No

Is there a whole house fan? Yes No

Describe the air intake system (outside air supply, cold air return, ductwork, etc.) and its condition where visible. Indicate the locations on the floor plan diagram.

_____

_____

_____

_____

_____

8. FACTORS THAT MAY INFLUENCE INDOOR AIR QUALITY

a) Is there an attached garage? Yes No

If yes, does it have a separate heating unit? Yes No

b) Are any petroleum-powered machines or vehicles stored in an attached garage (e.g., lawnmower, ATV, car) Yes No

c) Has the building ever had a fire? Yes No

d) Is there a fuel-burning or unvented gas space heater? Yes No

e) Is there a workshop or hobby/craft area? Yes No

If yes, where and what type? _____

f) Is there smoking in the building? Yes No

If yes, how frequently? _____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

g) Have cleaning products been used recently? Yes No

If yes, when and what type?_____

h) Have cosmetic products been used recently? Yes No

If yes, when and what type?_____

i) Has there been painting or staining in the last six months? Yes No

If yes, when and where? _____

j) Is there new carpet, drapes, or other textiles? Yes No

If yes, when and where? _____

k) Have air fresheners been used recently? Yes No

If yes, when and what type? _____

l) Is there a kitchen exhaust fan? Yes No

If yes, where is it vented?_____

m) Is there a clothes dryer? Yes No

If yes, is it vented outside? Yes No

n) Has there been a pesticide application? Yes No

If yes, when and what type?_____

_____

o) Are there odors in the building? Yes No

If yes, please describe: _____

_____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

p) Do any of the building occupants use solvents at work (e.g., chemical manufacturing or laboratory, auto mechanic or auto body shop, painting, fuel oil delivery, boiler mechanic, pesticide application, cosmetology)? Yes No

If yes, what types of solvents are used? _____

_____

If yes, are their clothes washed at work? Yes No

q) Do any of the building occupants regularly use or work at a dry-cleaning service? (Circle appropriate response.)

No Unknown

Yes, use dry-cleaning regularly (weekly)

Yes, use dry-cleaning infrequently (monthly or less)

Yes, work at a dry-cleaning service

r) Is there a radon mitigation system for the building/structure? Yes No

If yes, what is date of installation? _____ Active Passive

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

9. SAMPLE COLLECTION

This is to be completed by the sample collection team. On a separate sheet(s), provide a sketch of the building (including each floor as applicable), all (unremovable) potential indoor sources found in the building (including attached garages), the location of the source (floor and room), and each sample location (see below). Any ventilation implemented after removal of potential sources shall be completed at least 24 hours prior to the commencement of the indoor air sampling event.

Photographs should be taken at each sample location, and of any unremovable source, to supplement the documentation recorded below. The photographs must be of good quality and any labels must be legible.

Location	Sample ID	Sample Container Size	Sample Duration	Flow Rate Verification (Y / N)	Comments

Sampling Information:

Sample Technician: _____ Telephone No.:_____

Analytical Method: TO-15 / TO-17 / other: _____

Laboratory: _____

INDOOR AIR BUILDING SURVEY AND SAMPLING FORM (continued)

Were "Instructions for Occupants" followed? Yes No

If not, describe modifications:

_____

Was field screening performed? Yes No

If yes, describe Make and Model of field instrument used:

_____

Meteorological Conditions

Was there significant precipitation within 12 hours prior to (or during) the sampling event?
Yes No

Describe the general weather conditions:

_____

_____

General Observations:

Provide any information that may be pertinent to the sampling event and may assist in the data interpretation process.

_____

_____

_____

_____

Section II

Vapor Monitoring Wells and Implants

and

Sub-Slab Vapor Monitoring Point

The information contained in this Standard Operating Procedure (SOP) is drawn from existing manuals, various reference documents, and a broad range of colleagues with a considerable amount of practical and educational backgrounds. This SOP outlines the generic procedures necessary to install a soil gas probe, vapor monitoring point, or Sub-Slab vapor implant. Site conditions, contaminants, and geology may require modifications of this procedure

1. Soil Gas Probe and Vapor Monitoring Point

1.1. Soil Gas Probe Materials and Construction

***General Material List*:** Tubing, sand for sand pack around screen, bentonite pellets, and Swagelok fittings. Pictures of various probe materials are shown in Photos 1 and 2.

Tubing:

- Diameter: Nominally 1/8 inch outer-diameter (OD) or ¼ inch OD.
- Material: Nylon tubing is preferred over Teflon due to lower absorption rates. Nylon tubing is more flexible and easier to work with than stainless steel tubing. 1/8 inch OD nylon is easier to work with than ¼ inch OD tubing.

Screen:

- Types: Multiple types are available including stainless steel, aluminum, ceramic, and plastic. Actual screen utilized will depend on site conditions and contaminants.
- Length: Should not exceed six inches.

Surface Termination on Tubing: Swagelok fittings or valve

Surface Termination on Ground: Options include flush mounts on floor/surface, below ground-level with or without locking cover, and variable above ground-level completions

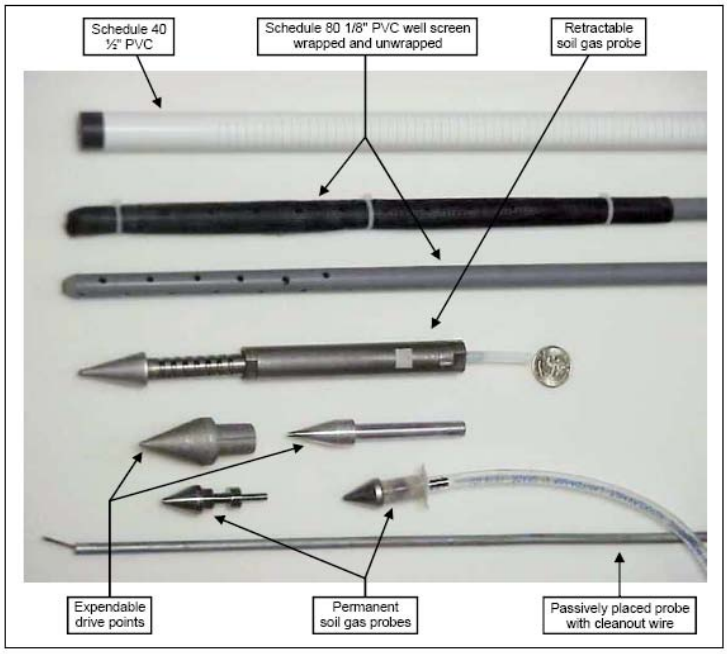
1.2. Probe Installation Protocol

Boreholes may be created with hand equipment (hand-auger) or direct-push systems. Tubing can be installed down a variety of boreholes ranging in diameter from 1 inch to 8 inches. Installation of several tubes in the same borehole at varying depths (hereafter referred to as nested vapor wells), are easier in boreholes >1.5 inch inter-diameter (ID). The following description infers that all utilities have been cleared and an open borehole exists. In situations where the borehole collapses; the same protocol can be followed down the probe rods, keeping care not to pull the tubing out when the rods are retracted and to add grouting materials as the rod is removed (Hartman, 2004b).

Photo 1

(Hartman, 2004b)

Photo 2



(NJDEP, 2005)

Photos 1 and 2 – Vapor probe materials, including various tips, and two types of terminations.

Methodology

1. Measure depth to bottom of boring.

2. Cut the probe tubing to appropriate length to reach base of boring and to give enough surface length for required type of surface termination (flush, recessed, and protruding).

3. Add about two inches of sand to bottom of borehole (calculate required volume based upon borehole ID).

4. Insert nylon tube with screen down borehole. If the boring is deep and narrow, adding a small inert weight (e.g., nut) may be utilized to facilitate tube reaching the bottom. Cover the top of the screen with a minimum of four to six inches of sand.

5. If a single depth vapor well point is to be set, grout to the surface using hydrated bentonite for a semi-permanent or temporary well installation that will not exceed <48 hours. For permanent or longer term installation the surface should be completed at the surface with a procover or surface mount that will protect it and provide limited access. General schematics of various vapor well completions are provided in Figures 1 and 2 below. Photos of surface completions for both temporary and permanent vapor wells are shown in Photos 3 through 5.

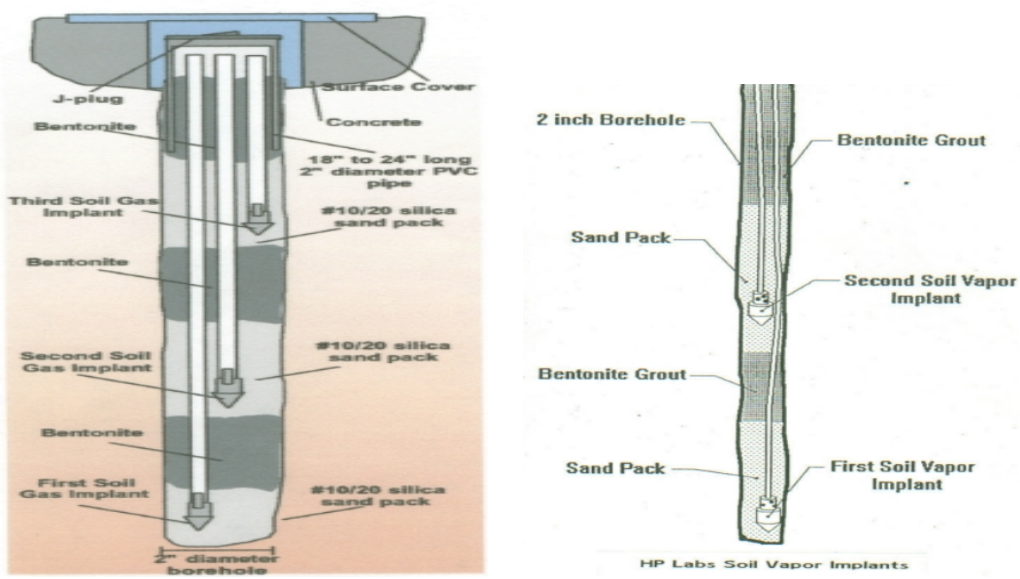
6. For nested vapor wells, add bentonite grout, hydrating periodically, to the next sample depth. Repeat steps 3, 4, and 6 until all sample depths are completed.

7. Cut the protruding lengths of tubing successfully shorter so the deepest sample tube is the longest length and the others progressively shorter. This is helpful if the labels on each tube are lost or illegible upon resampling.

8. Label each tube BEFORE installing the next tube. Labels should be attached to the tubing and not wrote directly on the tubing.

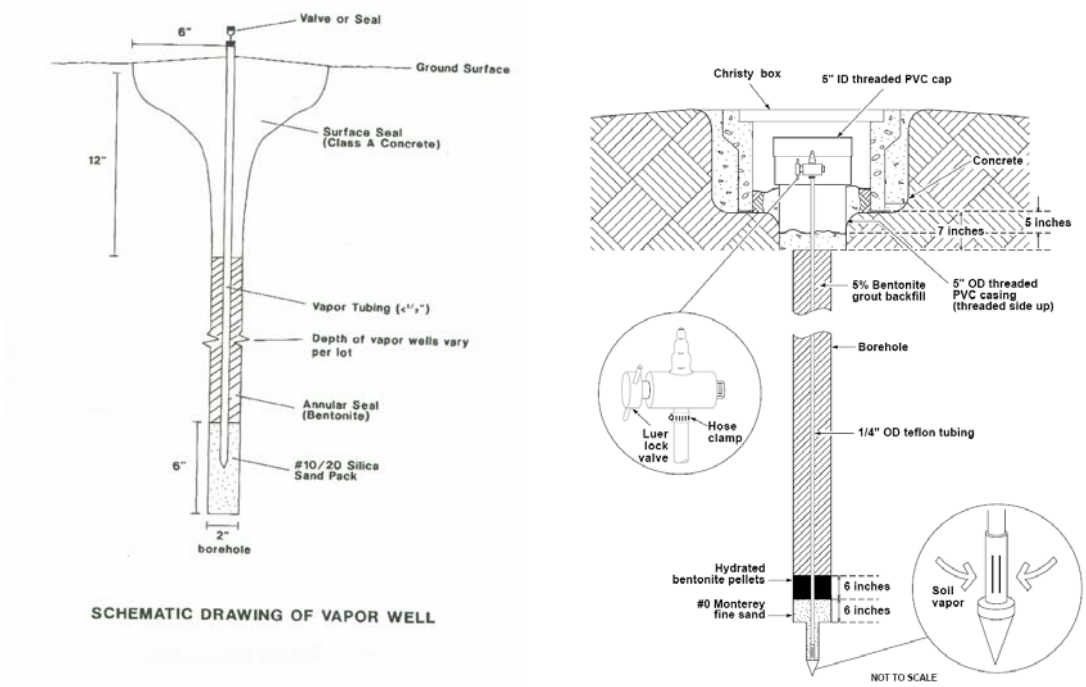
9. Terminate surface ends of tubes with Swagelok caps, valves, or other desired terminations.

Refer to Figures 1 and 2 for schematics and surface completion details and Photos 3-5 for pictures of completed nested wells.



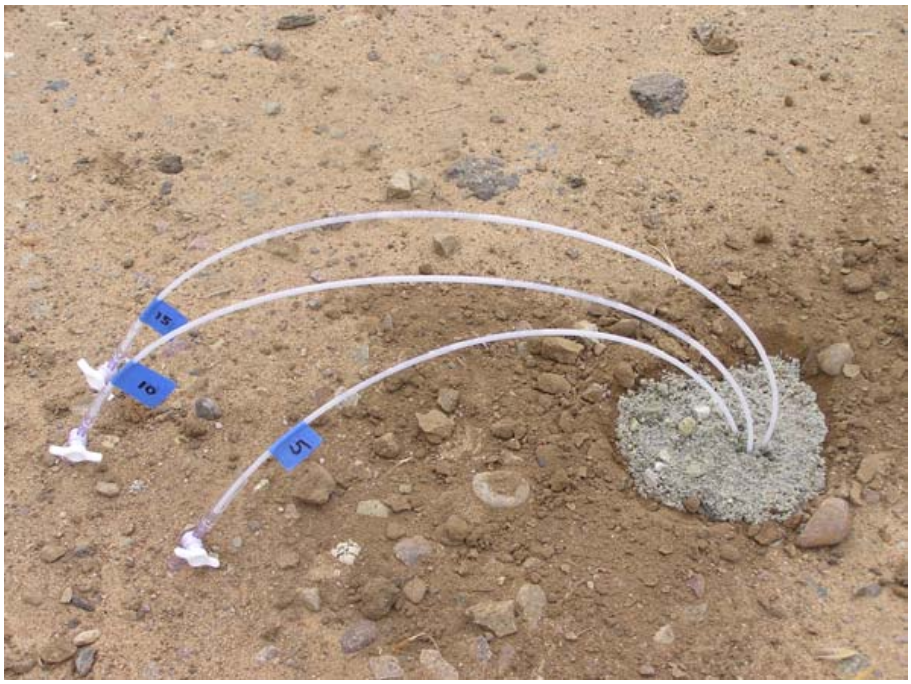
(Hartman, 2004b)

Figure 1 – Various schematics of nested wells.



(Hartman, 2004b) (Haar, 2000)

Figure 2 – Various surface completions for vapor wells.



(Hartman, 2004b)

Photo 3 – Completed nested temporary vapor well (3 depths). No surface completion.

(Hartman, 2004b)

Photo 4 – Nested vapor well with surface completion and locking well cap.

(Hartman, 2004b)

Photo 5 – Nested vapor well with flush surface completion and locking well cap

2. Sub-Slab Monitoring Point

2.1 Sub-Slab Monitoring Point Materials and Construction

General Material List: Tubing, sand for sandpack around screen, Swagelok fittings or valve. Pictures of various probe materials are shown in Photo 6, and typical installation is shown in Figure 3.

Tubing:

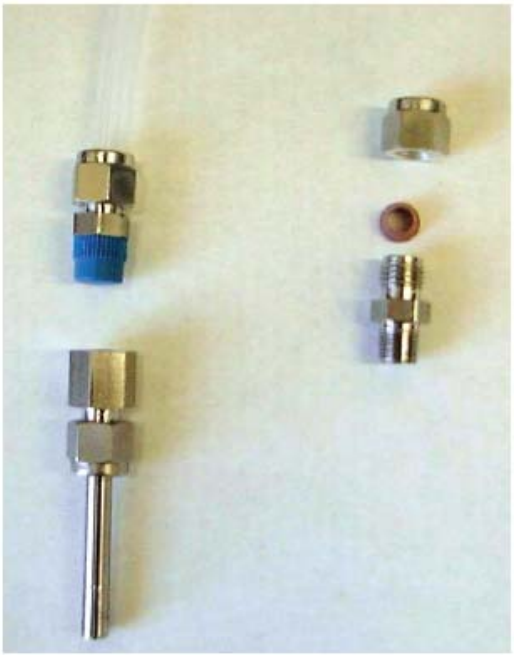
- Diameter: Nominally 1/8 inch OD or 1/4 inch OD.
- Material: Teflon tubing, nylon tubing, or stainless steel tubing. The small size and length of the tubing makes stainless steel the performed material.

Screen:

- Types: stainless-steel, aluminum, ceramic, plastic (typically no tip required for Sub-Slab), multiple types are available including stainless-steel, aluminum; ceramic, plastic, and typical installation will not include a tip.

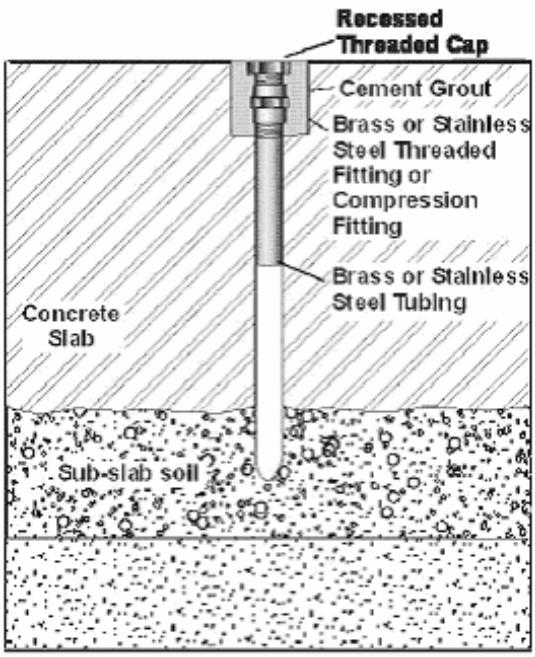
Surface termination on tubing: Swagelok fittings or valve.

Surface termination on ground: Options include flush mounts on floor and/or surface, below ground level with or without locking cover, variable above ground level completions (Hartman, 2004a).



(DiGiulio, 2007)

Photo 6 – Stainless-steel vapor implant (1/8 inch OD,) with sampling tubing and cap. Stainless-steel tubing can be cut to any length.



(DiGiulio, 2007)

Figure3–General schematics of Sub-Slab vapor point.

2.2 Sub-Slab Monitoring Point Installation Protocol

General Notes

- To minimize the potential for drilling through utility lines, local utility companies should be contacted to mark off entry points of water, gas, electrical, and sewer lines outside each building. It is often possible to see points of entry of gas, water, and sewer lines through basement walls and floors. Tracing utility lines inside a building with a slab on-grade is more difficult. In this case, a local plumber and electrician should be contacted to provide recommendations on safe locations to drill. Caution must be exercised when drilling through post-tensioned concrete. Post-tensioned methods are used to create monolithic slabs for house construction in locations where expansive soils damage foundations. The unbonded method allows individual cable movement relative to the concrete. If damaged, a cable can destress itself, burst out of the slab, and cause potential serious injury. Under these conditions, it may be preferable to avoid Sub-Slab sampling (DiGiulio, 2007).

- "Semi-permanent" probes are designed to allow repeated sampling over time and lie flush on the upper surface of a slab as to not interfere with daily use by homeowners. Use of a screen is unnecessary because the probe is not inserted directly into Sub-Slab material (DiGiulio, 2007).

- If threaded brass fittings and tubing, such as those obtained from a hardware store, are used for probe construction, equipment blanks should be collected to verify that construction materials are not a source of volatile organic compounds (VOCs) of concern. Residual cutting oil may be present on threaded fittings. To minimize this concern, it is preferable to construct probes from gas chromatography-grade stainless-steel fittings. The probe illustrated in Figure 3 was constructed from 2.5 centimeters (cm) (1 inch) long, 0.64 cm (1/4 inch) OD x 0.46 cm (0.18 inch) ID gas chromatography grade 316 stainless-steel

  Tubing and a 2.5 cm (1 inch) long, 0.64 cm (1/4 inch) OD x 0.32 cm (1/8 inch) Swagelok stainless-steel compression fitting. Probes should be assembled prior to the hole creation to minimize exposure time of sub-slab soils to ambient air (DiGiulio, 2007).

- A rotary hammer drill (Photo 7), can be used to create an "inner" and "outer" hole to set the probe in place (Photo 8). The larger diameter shallow outer hole should be drilled first and cleaned with a "clean" damp towel prior to drilling the deeper smaller diameter inner hole. A vacuum cleaner should not be used to remove cuttings as fractures in the concrete may avert air to the surface. When drilling the inner hole, the drill bit should penetrate an additional 5 cm (2 inch) into sub-slab material (e.g., sand or sand and gravel), to create an open cavity to prevent potential obstruction of probes during sampling (DiGiulio, 2007).

(DiGiulio, 2006)
Photo 7 – Drilling through a concrete slab using a rotary (1/2 inch OD)

(DiGiulio, 2006)
Photo 8 – "Inner" and "outer" holes drilled in a concrete slab

- If the probe will be removed immediately after sampling, bentonite or modeling clay can be used. Organic sealants should be avoided unless it can be demonstrated that they are free of VOCs of concern. The VOC-free water should be used for cement application (DiGiulio, 2007).

Methodology

1. Ensure all Sub-Slab utilities (public and building specific) are marked prior to installation.

2. Drill a ½ inch to 1 inch OD hole through the slab with a drill and spline bit. Do not use water. If dust prevention is necessary, cover the location with a towel/cloth and drill through a pre-cut hole in the cloth.

3. Measure slab thickness. Cut tubing to the appropriate length to reach the base of the slab and to give required type of surface termination (flush, recessed, protruding). If a flush or recessed surface termination is required, a larger diameter hole (1 inch), in the upper 1 inch of the slab may be useful to leave enough room for the fitting on the probe tubing.

(DiGiulio, 2006)

Photo 10 – Example of a Sub-Slab monitoring point being sampled by TO-15

Photo shows a brass to Swagelok union fitting was used to connect vapor probes to a "T" fitting made of a stainless-steel flexible line and an in-line valve. A portable vacuum pump was used to purge vapor probes and sampling lines. Samples were collected by closing the in-line valve on the pump end of the "T" fitting and opening a valve for entry into a 6-liter SilcoCan canister.

A particulate filter was attached to the inlet port. Samples were collected by opening the canister valve and waiting until the canister pressure approached atmospheric pressure (grab sampling).

4. Insert tubing. Add sand to cover tip of sampling point with about one inch of sand.

5. Grout to the surface using bentonite (if temporary installation), or cement (if permanent installation).

6. Wait 30 minutes prior to sampling.

7. Purge Sub-Slab sampling point.

8. Collect Sample.

3. Sample Collection

Most vapor wells are installed at relatively shallow depths (<5 feet (ft) below ground surface), so minimum purge volumes and low volume samples are preferred to minimize potential breakthrough from the surface or between sampling intervals. Tracer/leak gas is necessary to ensure breakthrough does not occur. A minimum of 60 minutes is required after the completion of the entire vapor point installation prior to the collection of any samples. Samples must not be collected for a minimum of 48 hours of any rain event and until site conditions (including moisture content), are returned to typical site conditions.

Table 1
Volumes for Select Tubing Sizes

Tubing Size (inches ID)	*Volume/ft (liters)*
3/16	0.005
1/4	0.010
1/2	0.039
3/4	0.087
1	0.150
2	0.620

Samples from wells with multiple points installed must not be collected simultaneously and approximately 30 minutes must elapse between each sampled interval. For larger canisters (> 1 liter), sample flow rates are not to exceed 200 milliliter (ml)/minutes to minimize potential for vacuum extraction of contaminants from the soil phase. Samples collected with canisters that collect a sample volume three times greater than the volume of the sampling point; must consider a volume test for the boring, to ensure sample dilution from other zones is not occurring. Volumes of various tubing sizes are provided in Table 1.

Tracer gases must be utilized during the collection of soil gas samples. Some tracer gases allow for field screening to correct any potential issues in the field. Though many of these compounds are readily available, quality of the tracer gas must be verified to ensure the lack of secondary contaminants in the tracer gas that may be similar to site COCs. The presence of the tracer compound in the analysis confirms a leak and another sample must be collected.

General Material List: Tubing to go from the monitoring point to the sampling apparatus, syringe for purging sampling point, sampling container applicable for appropriate sampling method, vacuum gauge, sampling train as necessary, and tracer gas.

Tubing:

- Diameter: nominally 1/8 inch OD or ¼ inch OD to match sampling well point
- Material: Nylon tubing is preferred over Teflon due to lower adsorption rates. Nylon tubing is more flexible and easier to work with than stainless steel tubing. 1/8 inch OD nylon is easier to work with than ¼ inch OD tubing.

Sampling Container:

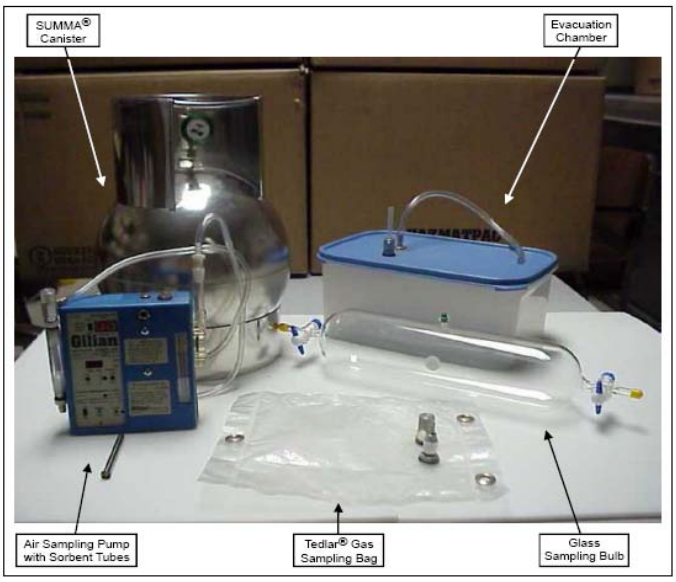
- Types: Depending on the analytical method utilized the sampling container, size, and number may vary (Photo 6).
    - TO-15 may be collected in container that range from 500 ml – 6 liters depending on the concentrations and contaminates present.
    - If canisters with flow chokes are used, ensure flow chokes are dedicated to the canister or cleaned before reuse on another canister.
    - TO-17 may require the collection of multiple Sorbent tubes from each vapor point as each Sorbent tube utilized may not be applicable for all compounds.
    - Use of Tedlar bags or syringes, due to extremely short holding times which have been documented for high losses of various VOCs is not recommended for samples collected for compliance sampling.
    - Please see Operational Memorandum 2 for more information on proper analytical procedures.

Vacuum gauge and sampling train:

- Various as required

Tracer Gas:

- Must be utilized. Laboratory should be consulted in using any compound to ensure that the selected compound is capable of being detected and that it is included in each analysis for verification of the field sampling methodology.



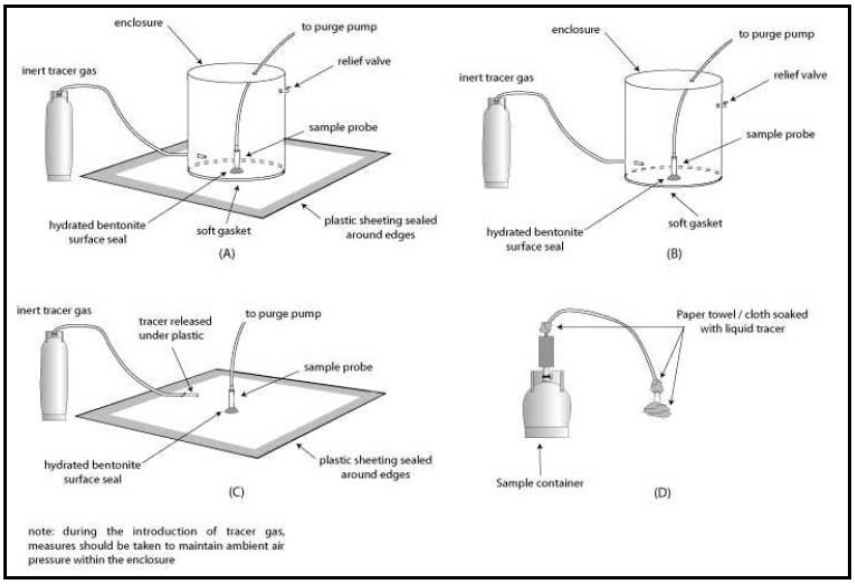
(NJDEP, 2005)

Photo 6 – Examples of various sampling containers.

Methodology

1. Assemble the aboveground sampling equipment which consists of connector tubing, regulated flow meter, pressure gauge, and purging equipment.

2. Connect aboveground sampling equipment to probe at the surface. Check all sampling system connections and fittings for tightness and obvious deterioration. Prior to collecting each sample, use a hand pump to vacuum test the sampling equipment after assembly.



(NYSDH, 2006)

Figure 4 - Various examples of utilizing a tracer.

3. Quick connect fittings and nylon tubing should be used to ensure vacuum tightness of the system and that chemicals in the air stream are not reacting with or adsorbing to the tubing. Compression fittings should be avoided for all connections except at the Summa canister (if used).

4. Purge at least three volumes of air from the sampling system. After purging is complete, close the valve to the purge line and/or disconnect purge apparatus, as appropriate.

5. Connect the sample container to the sampling line, using quick-connect, and airtight fittings.

6. Select a leak check compound that is not known or suspected to be site related or otherwise associated with the site or nearby properties.

7. Immediately before sampling, place the leak check compound at each location where ambient air could enter the sampling system or where cross contamination may occur.

For liquid compounds (for example, isopropanol), wet a paper towel with the leak check compound and place the towel over each location where ambient air could enter the sampling system. These areas include: the base of the soil probe at ground surface, the connection from the soil gas probe to the sampling line, and any connections within the sampling line. Leak check compounds that are vapors require a device to hold the vapor near the test location (such as a cover at the surface). See Figure 4.

8. The leak check compound must be included in the list of analytes looked for during laboratory analysis of each sample however, if the compound is able to be screened in the field it should be done, both before and after sample collection.

9. Open valve and collect sample into sample container, following the sample flow rate and vacuum guidelines discussed above. During sampling, measure and record sample flow rate and vacuum every two to five minutes.

10. Disconnect sample container and immediately label the container with sample identification information.

11. If Summa canisters are used, measure the final pressure of the canister using a pressure gauge. Record the final canister pressure.

12. Store sample containers out of direct sunlight and do not chill.

4. Quality Assurance and Quality Control Samples

The QA/QC must be an integral part of any sampling activities. The QA/QC procedures must be included in sampling activities to ensure the samples are representative of the subsurface conditions. A full QA/QC program should be implemented that includes the collection of at least one field duplicate per sampling event or one per 20 samples, whichever is greater. Duplicate samples shall be collected in separate sample containers, using the same procedures, at the same location, and depth as the original sample. Preferably, duplicate samples should be collected simultaneous to collection of the primary sample using a sampling tee. Alternatively, the duplicate may be collected immediately after the collection of the primary sample.

At least one equipment blank must be collected per sampling event or per 25 samples, whichever is greater.

5. Field Records

The following information should be recorded in a field notebook or on sampling forms similar to those shown in Figure 4 to document the procedures utilized at a specific site to collect soil gas data. In general the fields should include the following information:

Methodology

1. Sample identification information, including the locations and depths at which the samples were collected, sample identifiers, date, and time.

2. Identify the field personnel involved in sample collection.

3. Weather conditions (e.g., temperature, wind speed, barometric pressure, precipitation, etc.).

4. Sampling methods, devices, and equipment used.

5. Purge volumes prior to sample collection. Relate the purge volumes to the volume of the sampling equipment, including the tubing connecting the sampling interval to the surface.

6. Volume of soil gas extracted (i.e., volume of each sample).

7. Vacuum of canisters before and after samples collected.

8. Tracer gas utilized and whether it is a liquid or a solid.

9. Field screening of any tracer gas.

Shipment information, including chain of custody protocols, and records must also be followed.

Example Soil Gas Sampling Form

Date:		Sampler	
Project:		Project Number	
Container Type:		Container ID	
Sample ID		Depth of Sample	
Purge Volumes		Purge End Time	
Sample Start Time		Sampling End Time	
Tracer Gas Utilized:		Last known rain event	
Weather Conditions:		Other:	
Temperature:			

Sampling Device			
if by TO-15			
Canister Starting Pressure		Canister Ending Pressure	
Volume of Canister		Other:	
Regulator ID #			
if by TO-17			
Number of Containers		Other:	
Sorbents Utilized			
Tube ID Number			
Pump ID and Number			

Field Measurements

Time	Flow rate (mL/min)	Pressure (in H20)	Comments

Figure 5 – Example of Field Sampling Form

6. References

DiGiulio, D. 2007. "Sub-Slab Probe Installation," Submitted to AWMA's Specialty Conference on Vapor Intrusion: Learning form the Challenges, September 26-28, 2007, Providence, RI

DiGiulio, D.C.; Paul, C.J.; Cody, .R; Willey, R.; Clifford, S.; Kahn, P.; Mosley, R.; Lee, A.; and Christensen, K. 2006. Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples; U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, Ohio 2006; http://www.epa.gov/ada/download/reports/600R05147/600R05147.pdf.

Haar and Gregory, 2000 ERD SOP 1.10: Soil vapor Surveys – Revision: 4, Lawrence Livermore National Laboratory, Livermore Site and Site 300 Environmental Restoration Project, Standard Operating Procedures (SOPs).

Hartman, B.. 2004a. "Sub-Slab Soil Vapor Standard Operating Procedures," H&P Mobile Geochemistry, Solana Beach, California.

Hartman, B.. 2004b. "Vapor Monitoring Wells/Implants Standard Operating Procedures," H&P Mobile Geochemistry, Solana Beach, California.

New Jersey Department of Environmental Protection (NJDEP), 2005. Vapor Intrusion Guidance.

New York State Department of Health (NYSDH), Center for Environmental Health, Bureau of Environmental Exposure Investigation, 2006. Guidance for Evaluating Soil Vapor Intrusion in the State of New York.