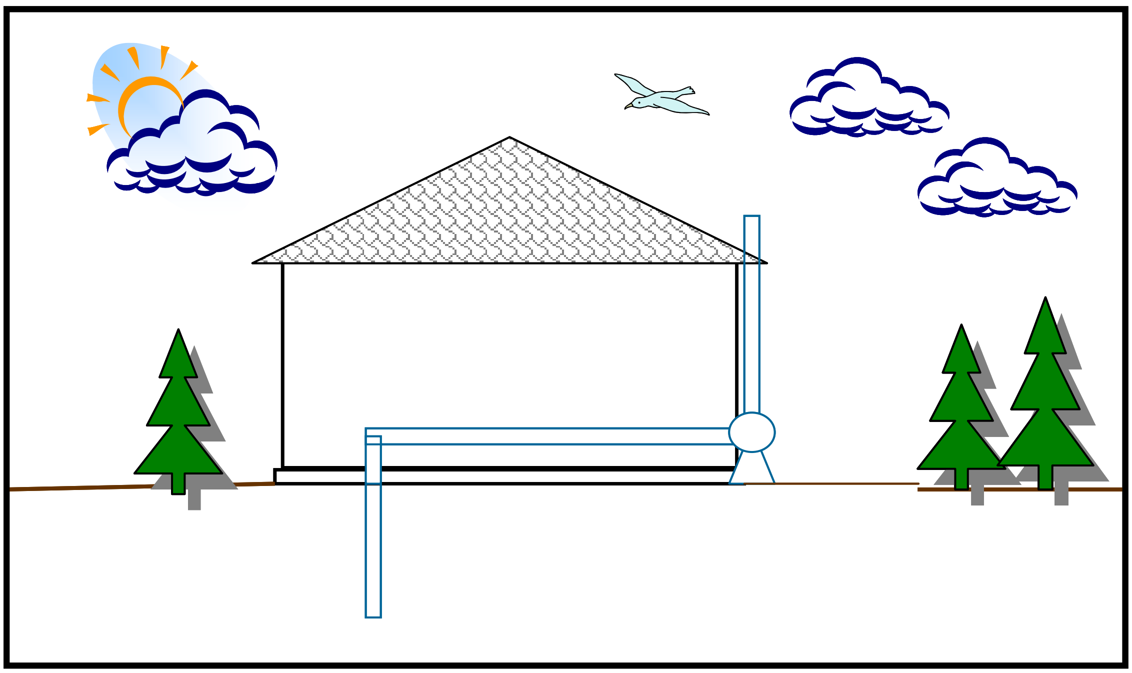
VAPOR INTRUSION MITIGATION ADVISORY



FINAL

REVISION 1

Department of Toxic Substances Control
California Environmental Protection Agency

October 2011

FOREWORD

The California Department of Toxic Substances Control (DTSC) is issuing this *Vapor Intrusion Mitigation Advisory* (VIMA or Advisory) for use on sites that may be impacted by soil vapor intrusion into indoor air. The mitigation alternatives described in the Advisory are response actions designed to interrupt or monitor the vapor intrusion pathway and to ensure public safety until the source of volatile chemical concentrations causing the vapor intrusion risk has been restored to concentrations at or below levels considered safe for human exposure.

DTSC developed the *Vapor Intrusion Mitigation Advisory* primarily as a guide for DTSC staff. Other agencies, environmental consultants, responsible parties, community groups, and property developers may find the Advisory useful.

Originally issued in April 2009, VIMA was available for public comment until November 30, 2009. DTSC reviewed the comments received and has incorporated appropriate changes into this revision. DTSC fully expects that users of the Advisory will continue to identify areas for improvement. Additionally, new and innovative technologies may result in developing mitigation approaches not anticipated at the time of publication. DTSC will update the Advisory as determined to be appropriate.

Please submit comments and suggestions for improvement of the *Vapor Intrusion Mitigation Advisory* to:

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ACKNOWLEDGMENTS

A document of this nature is never written in a vacuum. In preparing this document, the authors relied extensively on pre-existing documents for content and design. Rather than burden the reader with endless referrals within the text to other documents, the most often-used reference materials include the following:

Interstate Technology and Regulatory Council – Vapor Intrusion Team. 2007. *Vapor Intrusion – A Practical Guide*.
Massachusetts Department of Environmental Protection. 1995. *Guidelines for the Design, Installation and Operation of Sub-Slab Depressurization Systems*.
United States Environmental Protection Agency. 2008a. *Brownfields Technology Primer: Vapor Intrusion Considerations for Redevelopment*.
United States Environmental Protection Agency. 2008b. *Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches*.
New York State Department of Health. 2006. *Final Guidance for Evaluating Soil Vapor Intrusion in the State of New York*.
Colorado Department of Public Health and Environment. 2004. *Draft Indoor Air Guidance*.

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This Advisory has benefited greatly from input provided by several sources, including:

- VIMA-at-large members, an internal technical advisory group focused on vapor intrusion mitigation
- DTSC's Proven Technologies and Remedies Team
- Director's Brownfields Revitalization Advisory Group
- Internal and external reviewers of draft versions of the Advisory

In particular, the authors wish to thank the following DTSC individuals for their contributions to the development of this Advisory: Mr. Stewart Black, Mr. Paul Carpenter, Mr. Dan Gallagher, Dr. Debbie Oudiz, Mr. Roger Paulson, Mr. Tim Patenaude, Mr. Chris Siembab, Mr. Jesus Sotelo, and Ms. Kathaleen Reed.

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ACRONYMS AND ABBREVIATIONS

AB 422	California Assembly Bill 422
APCD	Air Pollution Control District
AQMD	Air Quality Management District
ASTM	ASTM International (formerly known as American Society of Testing and Materials)
Cal/EPA	California Environmental Protection Agency
CEQA	California Environmental Quality Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHHSL	California Human Health Screening Level
CMS	corrective measures study
CSM	conceptual site model
DTSC	California Department of Toxic Substances Control
EE/CA	engineering evaluation/cost analysis
EIR	environmental impact report
FS	feasibility study
HI	hazard index
HSAA	Hazardous Substance Account Act
HSC	California Health and Safety Code
HVAC	heating, ventilation, and air conditioning
HWCL	Hazardous Waste Control Law
IC	institutional control
IM	interim measure
ITRC	Interstate Technology and Regulatory Council
LARWQCB	Regional Water Quality Control Board, Los Angeles Region
LEL	lower explosive limit
LUC	land use covenant
NFPA	National Fire Prevention Association
O&M	operation and maintenance
PCE	tetrachloroethene
QA	quality assurance
QC	quality control
RAP	remedial action plan
RAW	removal action workplan
RCRA	Resource Conservation and Recovery Act
RWQCB	Regional Water Quality Control Board
SMD	submembrane depressurization
SSD	sub-slab depressurization
SSP	sub-slab pressurization
SSV	sub-slab venting
TCE	trichloroethene
USEPA	U.S. Environmental Protection Agency
VI	vapor intrusion
VIMA	*Vapor Intrusion Mitigation Advisory*
VOC	volatile organic compound

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (USEPA) defines vapor intrusion (VI) as the migration of volatile chemicals from the subsurface into overlying buildings (USEPA, 2002). The California Department of Toxic Substances Control (DTSC) developed this *Vapor Intrusion Mitigation Advisory* (VIMA or Advisory) to assist with selecting, designing, and implementing appropriate response actions for sites where a potential VI risk has been identified for occupants of existing or future buildings. The VIMA draws on: DTSC's experience with response actions that involve mitigation of VI risk at sites with methane and other volatile chemicals in the subsurface; industry mitigation standards for radon; and the experiences of other agencies with VI.

This Advisory assumes that the steps in the *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion into Indoor Air* (Vapor Intrusion Guidance; DTSC, 2011) have been followed, and mitigation measures have been recommended to protect human health. Thus, the project would currently be at Step 11 which is "*mitigate indoor air exposure, monitoring, and implementation of engineering controls*." Hence, DTSC staff, stakeholders, and responsible parties may use the VIMA when 1) risk accorded to VI has been estimated by modeling or indoor air sampling; and 2) mitigation has been proposed as part of a response action.

The goal of a VI mitigation system is to mitigate the intrusion of subsurface contaminant vapors to indoor air and prevent human exposure at unacceptable levels. A VI mitigation system is implemented to reduce contaminant entry into the building until the subsurface contamination is remediated or no longer poses a significant risk to human health. Remediation and mitigation are complementary components of a volatile chemical response action, addressing cleanup of subsurface contamination and impacts to the human receptor via the VI pathway, respectively. DTSC does not consider a VI mitigation system as a means of remediating the source of the subsurface contamination.

Scope and Objectives

As illustrated in Figure ES-1, the VIMA provides a framework that guides the reader through the decision process for 1) determining if mitigation is appropriate for the project site, 2) selecting a mitigation system that is protective of human health, and 3) ensuring that implementation is sustainable for the duration of mitigation. The objectives of the VIMA are to:

- Summarize the risk management framework where VI mitigation decisions are made with technical soundness and consistency;
- Provide descriptions of various mitigation technologies to assist in response action selection;
- Describe the mitigation technologies most likely to be chosen (sub-slab depressurization [SSD] or sub-slab venting [SSV] systems);

- Provide guidance and design detail for installation of SSD and SSV systems and other mitigation technologies;
- Provide guidance for establishing operation and maintenance (O&M) requirements for VI mitigation technologies; and
- Provide guidance for implementation measures and other considerations.

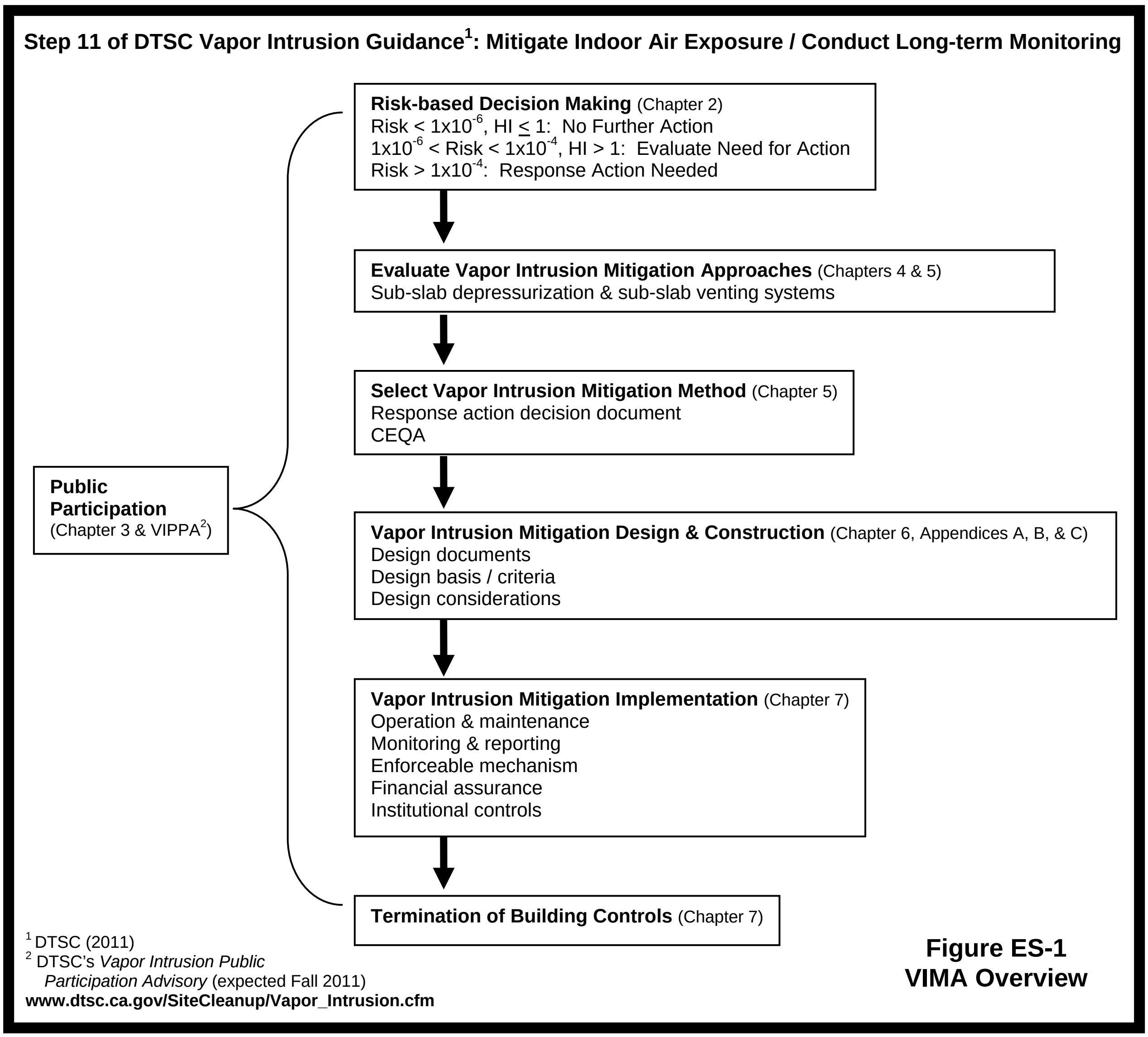

Figure ES-1
VIMA Overview

Risk-Based Decision Making

The specific action(s) taken to address VI from a subsurface source will depend on the estimated risk and hazard levels. The VIMA identifies potential response actions, based on the risk and hazard levels, to address the VI pathway. The need for a specific response action should be made on a case-by-case basis using multiple lines of evidence, as established in the Vapor Intrusion Guidance.

No Further Action (Risk $< 1x10^{-6}$; HI ≤ 1). If the estimated cancer risk is less than $1x10^{-6}$ and the noncancer hazard index (HI) is less 1, no further action is necessary under the DTSC cleanup process.

Risk Management Decision ($1x10^{-6} <$ Risk $< 1x10^{-4}$; HI > 1). The point of departure for risk management decisions for cancer risk is $1x10^{-6}$ and for noncancer hazard is an HI greater than 1. Sites with risk or hazard from volatile chemicals in excess of these points of departure will require a response action and long-term environmental care. Potential response actions could include: continued monitoring (e.g., soil gas, sub-slab or crawl space vapor, indoor air quality), installation of a VI mitigation system (such as a SSV or SSD system), and source remediation.

Mitigation/Source Remediation (Risk $> 1x10^{-4}$). If the measured or predicted volatile chemical concentrations in indoor air, as contributed by subsurface VI, are estimated to pose a potential risk to human health above $1x10^{-4}$, both source remediation and VI mitigation may be needed. The timing of this response action will depend on whether it is an existing building or if future development will proceed before remedial goals are met. The decision to implement a mitigation action should be based on multiple lines of evidence to evaluate potential human health risks from VI. DTSC must approve an appropriate response action decision document for any mitigation action (see Chapter 5).

The specific action(s) taken to address VI will also depend on site-specific considerations, such as:

- off-site sources of volatile chemical contamination
- ambient/background air[1] sources
- new building indoor air sources
- flexibility for proposed building placement or building use
- the results of a detailed evaluation of the VI pathway using site-specific parameters and multiple lines of evidence

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[1] For the purposes of the VIMA, ambient air is used to refer to the outdoor air in the neighborhood or community. The glossary of terms provides a more detailed definition of ambient air.

Public Participation Considerations

More extensive outreach typically is necessary for VI-impacted sites than may be needed for sites affected by other exposure pathways. The communication process should continue after a VI mitigation system is installed in a building and throughout its operation. DTSC's *Public Participation Policy and Procedures Manual* (DTSC, 2001; revision pending) should be followed. Additionally, DTSC's *Vapor Intrusion Public Participation Advisory* provides guidance specific to VI-impacted sites. Discussions of public participation considerations can be found in Chapter 3 (briefly) and in DTSC's *Vapor Intrusion Public Participation Advisory*.

Vapor Intrusion Mitigation Methods

Although several mitigation methods are available (see Chapter 4), the most commonly accepted mitigation techniques are systems that dilute contamination by ventilation (SSV) and systems that reduce contamination by lowering pressure (SSD systems) (USEPA,2008b).

- A SSV system is typically designed to function by venting sub-slab soil gases or providing a pathway to allow soil gas to migrate to the exterior of the building rather than entering a building. SSV systems function by drawing in outside air to the sub-slab area, which dilutes and reduces volatile chemical concentrations.
- A SSD system is designed to function by continuously creating a lower pressure directly underneath a building floor relative to the pressure within a building. The resulting negative pressure beneath the slab prevents soil gases from flowing into the building, thus reducing entry of volatile chemicals into the building.

Although these two systems are the focus of this document, the VIMA encourages innovation and the implementation of new, more effective and more sustainable approaches to VI mitigation, as they become available.

Evaluation of Vapor Intrusion Mitigation Approaches

A range of mitigation approaches should be evaluated to determine which is the most feasible. The screening, detailed analysis and selection of the VI mitigation technologies should be documented in an appropriate response action selection document (e.g., feasibility study, corrective measures study, remedial action plan, removal action workplan). DTSC prepares necessary documents to meet the requirements of the California Environmental Quality Act (CEQA) concurrently with the response action selection document.

Vapor Intrusion Mitigation System Design

All VI mitigation systems should be designed in conformance with standard engineering principles and practices. The responsible party should submit design documents for the VI mitigation system to DTSC for review and approval. Several factors should be considered in the mitigation system design, including:

- Coordination with active site remediation efforts;
- Source concentrations and type of volatile contaminants;
- Subsurface physical conditions (e.g., depth to water, soil properties, presence of utilities corridors);
- Integration of the system into the overall building design;
- Incorporation of monitoring devices and alarms;
- Potential for back drafting and short circuiting with SSD systems;
- Potential safety and environmental hazards (such as physical hazards to occupants, concentrations above the lower explosive limit, presence of asbestos);
- Assumptions and criteria to be met by VI mitigation;
- Construction quality assurance/quality control testing;
- Long-term maintenance and management requirements;
- Installation of sampling ports for sub-slab and/or crawl space vapor monitoring;
- For existing buildings, inspection of the building foundation for points of entry and quantification of building air flow characteristics; and
- For future developments, provisions to prevent the migration of vadose zone soil gas through utility trenches and channels.

Vapor Intrusion Mitigation Implementation

Implementation of a VI mitigation system has multiple considerations.

Operation and Maintenance. The VI mitigation system should have an effective O&M Plan. Key elements of this plan include: performance goals and measures; routine monitoring of volatile chemical concentrations and operational parameters; periodic indoor air monitoring; and a contingency plan.

Reporting. The responsible party should submit VI mitigation documents to DTSC for review and approval. Examples of these documents include design and construction/installation reports, sampling and analysis plans, a completion report, and periodic monitoring reports.

Inspections. Routine inspections should be conducted to ensure that site conditions have not changed and that the mitigation system components have not degraded. The inspection frequency is selected based on site-specific considerations.

Enforceable Mechanism. For O&M, DTSC will enter into an enforceable mechanism to address DTSC oversight and cost recovery. Examples of enforceable mechanisms include a corrective action consent agreement, consent order, consent agreement, voluntary cleanup agreement, and an O&M agreement.

Financial Assurance. The responsible party or site owner/operator should establish and maintain a financial assurance mechanism for costs associated with implementation of the VI mitigation response action, O&M activities, land use covenant (LUC) compliance, five-year reviews, and DTSC oversight.

Access Agreement. An access agreement is obtained prior to entering a building for testing and/or construction. For future buildings, access issues should be addressed in the LUC.

Institutional Controls. DTSC identifies institutional controls in the "Covenant to Restrict Use of Property, Environmental Restriction" (often referred to as a LUC). The responsible party should utilize a LUC with prescribed notifications, prohibitions, and engineering controls to ensure O&M and disclosure to future buyers and occupants.

Emissions and Discharges. The need for air permits and/or exhaust gas controls for the VI mitigation method should be determined on a site-specific basis.

Coordination with Other Agencies. Coordination with one or more other state and local agencies that have jurisdiction will be needed for most sites requiring VI mitigation.

Five-Year Reviews. Under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and state law, five-year reviews are required for a response action that results in hazardous substances remaining at the site above levels that would preclude unrestricted land use. The purpose of the five-year review is to ensure that the response action 1) remains protective of human health and the environment, 2) is functioning as designed, and 3) is maintained with appropriate O&M activities.

Termination of Building Controls. Subsurface remediation efforts will eventually reduce volatile chemical concentrations in soil, soil gas, and/or groundwater to levels that no longer require mitigation. At this point, the VI mitigation system could be shutdown and/or removed and O&M requirements would cease. The implementation plan for the VI mitigation system should include specific provisions for determining that subsurface remediation is complete and that the VI mitigation system is no longer needed. A confirmation sampling and analysis plan for soil, soil gas, and/or groundwater should be a part of these provisions.

1.0 INTRODUCTION

The California Department of Toxic Substances Control (DTSC) developed this *Vapor Intrusion Mitigation Advisory* (VIMA or Advisory) to assist with selecting appropriate mitigation and implementation measures for sites with a vapor intrusion (VI) risk. The Advisory is to be used when mitigation for VI has been proposed to address regulatory requirements. The Advisory discusses the approach which is applicable at any site where there is a VI risk to occupants of existing or future buildings.

The United States Environmental Protection Agency (USEPA) defines VI as the migration of volatile chemicals from the subsurface into buildings (USEPA, 2002). Volatile chemicals may include gases, volatile organic compounds (VOCs), select semivolatile organic compounds, select polychlorinated biphenyls, and some inorganic analytes (such as elemental mercury and hydrogen sulfide). For the remainder of the VIMA, all of these compounds will be collectively referred to as volatile chemicals. If the primary constituent of concern is methane, the DTSC's *Advisory on Methane Assessment and Common Remedies at School Sites* (DTSC, 2005) should be consulted rather than the VIMA document.

Vapor intrusion should be evaluated initially by developing a conceptual site model (CSM) and investigating and characterizing a site. An essential part of all site investigations, the CSM provides a conceptual understanding of the potential for exposure to hazardous chemicals at a site based on the sources of contamination, release mechanisms, transport media, and exposure pathways. A well-developed CSM should include all potential exposure pathways at the site, and should not be specifically limited to VI. The *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion into Indoor Air* (Vapor Intrusion Guidance; DTSC, 2011) provides the investigative steps for completing an initial VI analysis, including guidance on developing a CSM.

1.1 PURPOSE AND OBJECTIVES

The VIMA provides the decision-making guidance needed to effectively mitigate the intrusion of subsurface contaminant vapors to indoor air, and thus prevent human exposure at unacceptable levels. To that end, the VIMA draws on DTSC's experience with mitigating VI risk at sites with methane and volatile chemicals in the subsurface, as well as industry mitigation standards developed for radon in the 1980s. The VIMA also encourages innovation and the implementation of new, more effective and more sustainable approaches to VI mitigation, as they become available.

DTSC developed the VIMA primarily as a guide for DTSC staff, but other agencies, environmental consultants, responsible parties, community groups, and property developers may use the Advisory. The VIMA assists the project team with making informed, technically-sound decisions. The Advisory offers guidance in selecting appropriate technologies in consultation with engineering and risk management professionals. VIMA provides generally applicable engineering details rather than detailed engineering protocols.

The objectives of the VIMA are to:

- Summarize the risk management framework where VI mitigation decisions are made with technical soundness and consistency;
- Provide descriptions of various mitigation technologies to assist in response action selection;
- Describe the mitigation technology most likely to be chosen (sub-slab depressurization [SSD] or sub-slab venting [SSV] systems);
- Provide guidance and design detail for installation of SSD and SSV systems and other mitigation technologies;
- Provide guidance for establishing operation and maintenance (O&M) requirements for VI mitigation technologies; and
- Provide guidance for implementation measures and other considerations.

1.2 SCOPE AND APPLICABILITY

This Advisory assumes that the steps in the Vapor Intrusion Guidance have been followed, and mitigation measures have been recommended to protect human health. Thus, the project would currently be at Step 11 (see Figure 1) of the Vapor Intrusion Guidance which is "*mitigate indoor air exposure, monitoring, and implementation of engineering controls*." The VIMA provides a framework that guides the reader through the decision process for 1) determining if mitigation is appropriate for the project site, 2) selecting a mitigation system that is protective of human health, and 3) ensuring implementation is sustainable for the duration of the exposure.

The reader should keep in mind the distinction between "mitigation" and "remediation" as used in this Advisory. The VIMA uses "remediation" to refer to those parts of a response action that address cleanup of the subsurface to response action-based goals, either by *in situ* or *ex situ* techniques. The purpose of remediation is to reduce the level of contamination in the environmental medium that is acting as a source of indoor air vapors. In contrast, "mitigation" as used in this Advisory, is applied to actions that reduce contaminant entry into building structures or remove contaminants after they have entered a building. See Chapter 4 for a discussion of current mitigation strategies. This Advisory also addresses a third approach, which is to impose a land use covenant (LUC) in order to restrict residential use of a site.

It is important to keep two other points in mind when using this Advisory. First, "response action", as used herein, means hazardous waste facility closure, corrective action, remedial or removal action, or other response action to be undertaken pursuant to division 20 of the California Health and Safety Code. Other agencies, such as the Regional Water Quality Control Board (RWQCB), will conduct response actions in accordance with their particular regulations, such as the Water Code. Second, the term

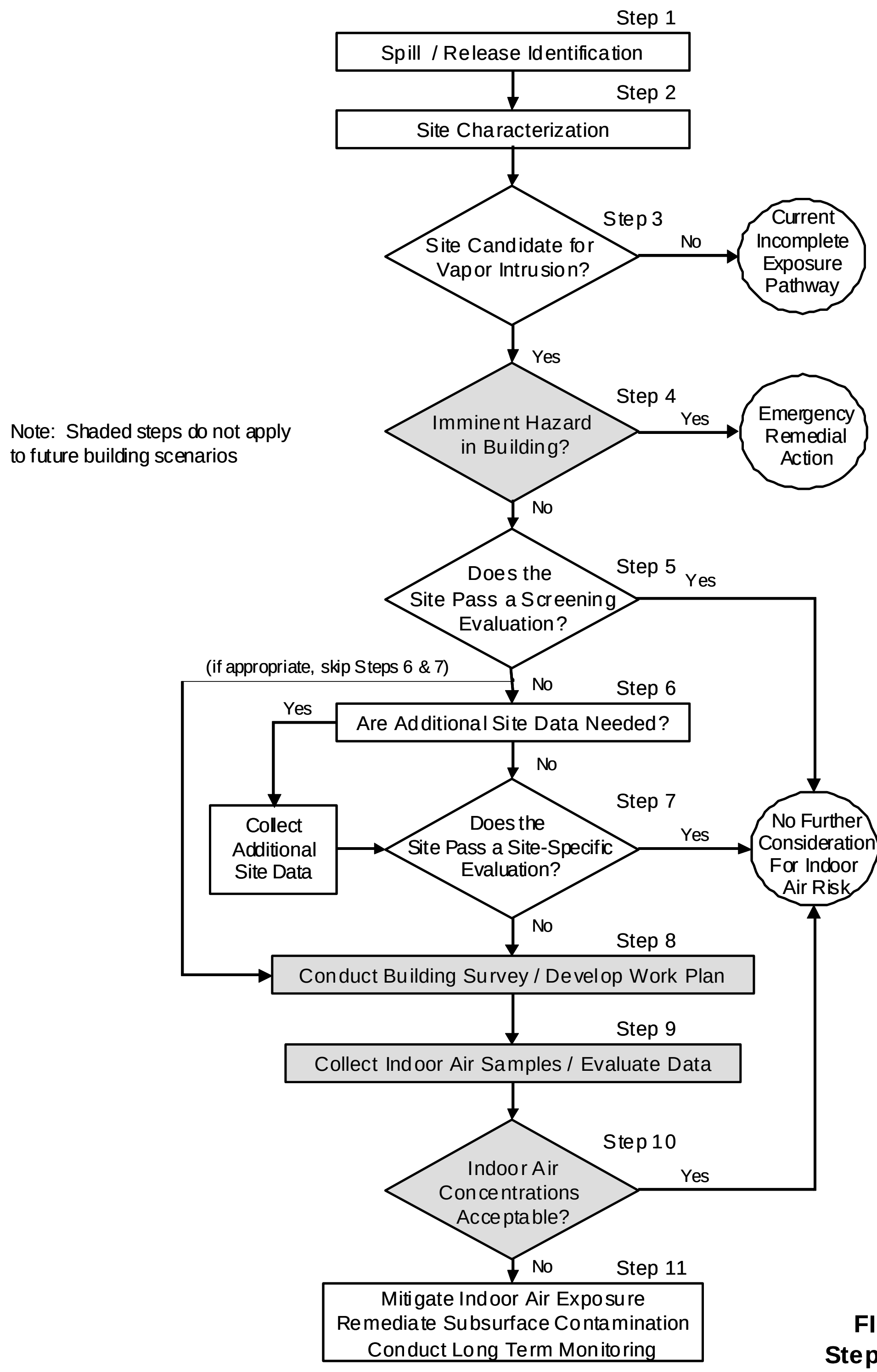


FIGURE 1
Steps in DTSC Vapor Intrusion Guidance Process*

*From DTSC (2011)
www.dtsc.ca.gov/SiteCleanup/Vapor_Intrusion.cfm

“buildings” includes any structure in which current or future occupants could potentially contact contaminated indoor air.

The VIMA provides technically defensible and consistent approaches for mitigating VI to indoor air, based upon current understanding of the exposure pathway. The VIMA is not regulation, nor does it impose any requirements or obligations on the regulated community. Rather, it provides a technical framework and reference for addressing VI mitigation. Other technically equivalent procedures exist, or may be developed, and this Advisory is not intended to exclude alternative approaches or the implementation of new, more effective approaches to VI mitigation. Hence, users of the VIMA are free to apply other technically sound approaches that may not be included in this document.

1.3 VIMA RELATIONSHIP TO OTHER GUIDANCE DOCUMENTS

Numerous guidance documents, both state and national, are available to assist in VI evaluation. The VIMA is one of several Cal/EPA documents pertaining to VI evaluation. The following documents are available as guidance for investigating soil gas, evaluating the potential for VI, and remediating sources of volatile chemicals:

- *Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion into Indoor Air* (Vapor Intrusion Guidance)
- *Advisory – Active Soil Gas Investigations*
- *Vapor Intrusion Mitigation Advisory*
- *Vapor Intrusion Public Participation Advisory*
- *Proven Technologies and Remedies Guidance -- Remediation of Chlorinated VOCs in Vadose Zone Soil*

Figure 2 illustrates where the Cal/EPA documents apply to the process identified in the Vapor Intrusion Guidance.

In addition, the California Environmental Protection Agency (Cal/EPA) developed California Human Health Screening Levels (CHHSLs) for volatile chemicals in soil gas that might migrate to indoor air. The CHHSLs are described in *Use of California Human Health Screening Levels (CHHSLs) in Evaluation of Contaminated Properties* (Cal/EPA, 2005) and are available on the Cal/EPA web-site. The CHHSLs were based on practical modeling for estimating indoor air concentrations from soil gas concentrations, standard exposure assumptions, and chemical toxicity values published by the USEPA and the Cal/EPA.

The documents described above will provide an overall conceptual understanding of the VI exposure pathway. Responsible parties involved in investigating or evaluating sites with VI concerns are encouraged to review these documents. Chapter 8 includes a list of other useful resources and website links.

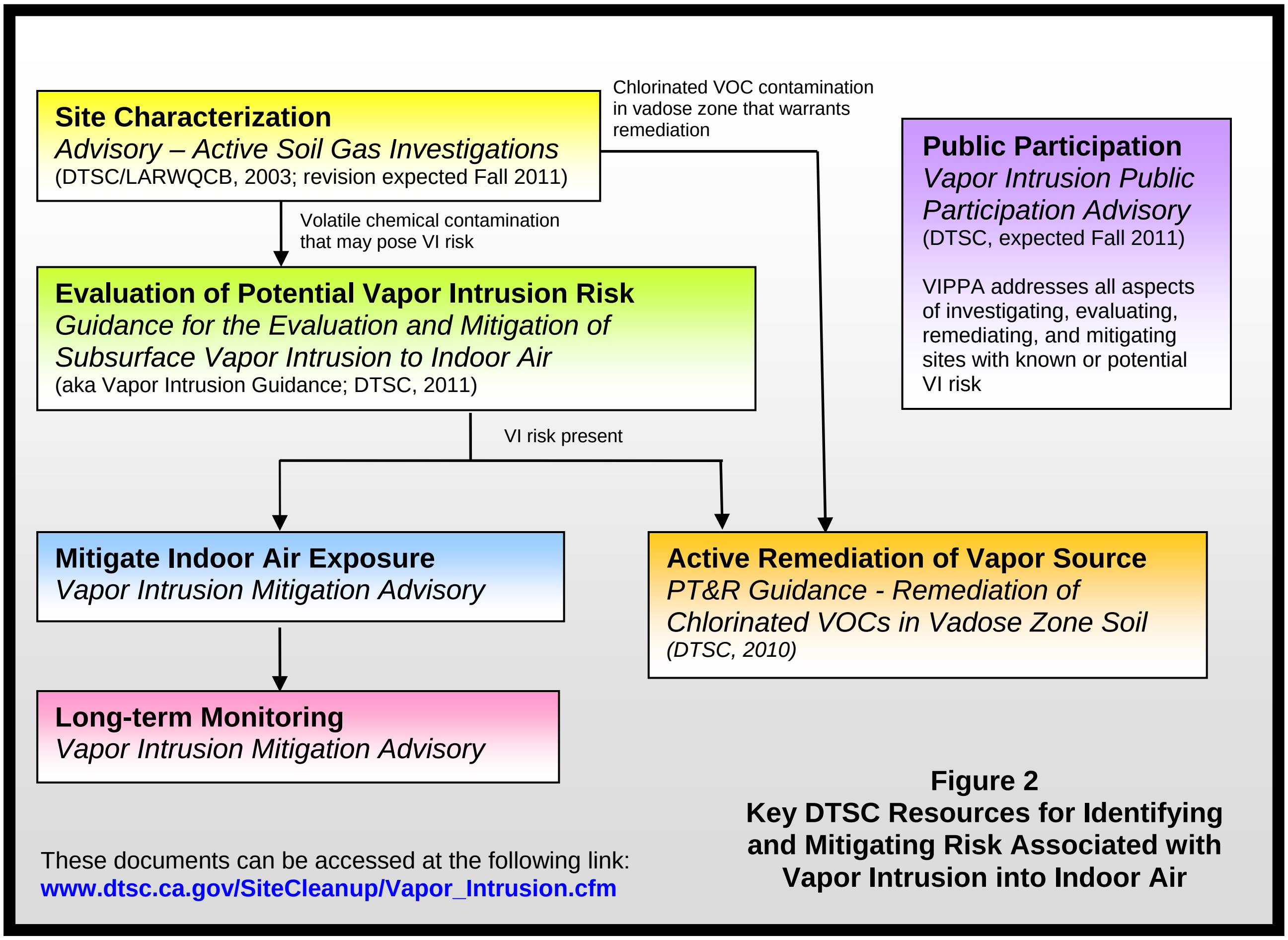


Figure 2
Key DTSC Resources for Identifying and Mitigating Risk Associated with Vapor Intrusion into Indoor Air

1.4 DTSC REGULATORY AUTHORITY

The California legislature passed Assembly Bill 422 (AB 422) in October 2007, amending Section 25356.1.5 of the California Health and Safety Code, and adding Section 13304.2 to the Water Code. AB 422 requires that the exposure assessment of any health or ecological risk assessment prepared in conjunction with a response action taken or approved pursuant to the California Superfund Act include the development of reasonable maximum estimates of exposure to volatile chemicals that may enter structures that are on the site, or that are proposed to be constructed on the site, and may cause exposure due to accumulation of volatile chemicals in the indoor air of these structures.

1.5 PREEMPTIVE APPLICATIONS OF VAPOR INTRUSION MITIGATION APPROACHES

The responsible party may propose VI mitigation as a preemptive solution for a perceived rather than actual threat, even in cases where DTSC is not requiring mitigation. The following scenarios provide examples in which preemptive solutions might be applied:

- A site where no building yet exists and fate and transport modeling indicates an acceptable risk (determined to be at or less than a 1 x 10^{-6} risk level or a hazard index (HI) of 1) to future building occupants. However, as a prudent measure, a developer is interested in installing VI mitigation measures despite the apparent low risk.
- An existing building overlies, or is in close proximity to, subsurface contamination, but the calculated risk level is less than or equal to 1 x 10^{-6} or a HI less than or equal to 1, and DTSC does not require mitigation.
- A site that is currently not impacted by a groundwater plume, but that may be impacted in the future.

In these instances, the project proponent may choose to follow the DTSC remedial process discussed in Chapter 5, even though the project does not involve DTSC review. Additionally, much of the information provided in the Advisory is general in nature, and may be helpful in the design and implementation of preemptive VI mitigation measures. However, for such preemptive applications, DTSC will neither approve nor enforce the mitigation, and will not be involved in the O&M for the mitigation system.

1.6 OVERVIEW AND ORGANIZATION

The VIMA provides a framework for selecting an appropriate mitigation approach at sites with a VI risk. This document includes questions as well as recommendations that should lead to logical and informed decisions resulting in the protection of human health.

Chapter 2 is a discussion of managing risk to current and future building occupants from VI.

Chapter 3 provides a brief introduction to public participation considerations for VI-impacted sites and directs the reader to DTSC's *Vapor Intrusion Public Participation Advisory*.

Chapter 4 discusses VI mitigation methods with a focus on SSV and SSD systems.

Chapter 5 describes the process for evaluating and selecting an appropriate mitigation system.

Chapter 6 describes design considerations for VI mitigation approaches.

Chapter 7 is a discussion of various aspects to consider during implementation, such as institutional controls, O&M, inspections, five-year reviews, financial assurance, and termination of building controls.

Chapter 8 includes a list of technical resources available for additional study and the references cited in the VIMA.

2.0 RISK-BASED DECISION MAKING FOR VAPOR INTRUSION SITES

If volatile chemical contamination is suspected at the site, the early stages of project scoping should address the potential for VI. This chapter discusses the risk management considerations associated with evaluating and responding to potential VI.

2.1 EVALUATION OF VAPOR INTRUSION PATHWAY

If volatile chemicals are present in the subsurface at a site, the VI pathway should be evaluated using the step-wise approach described in the Vapor Intrusion Guidance. As illustrated in Figure 1, different steps apply to existing and proposed buildings. Refer to the Vapor Intrusion Guidance for a detailed discussion of Steps 1 through 10. The VIMA provides detailed discussion of Step 11.

2.2 RESPONSE ACTIONS AT VAPOR INTRUSION SITES

Table 1 summarizes the basic decision logic used: 1) to evaluate subsurface contaminant data (e.g., soil gas and/or shallow groundwater) and/or indoor air sampling data at potential VI sites; and 2) to identify an appropriate response action. The need for a specific response should be made on a case-by-case basis using multiple lines of evidence, as established in the Vapor Intrusion Guidance.

Table 1. Risk Management Matrix for Vapor Intrusion

VAPOR INTRUSION RISK / HAZARD[1]	RISK MANAGEMENT DECISION	ACTIVITIES
Risk < $1x10^{-6}$ Hazard Index ≤ 1.0	No Further Action	• None
$1x10^{-6}$ < Risk < $1x10^{-4}$ Hazard Index > 1.0	Evaluate Need for Action	Possible Actions: • Additional Data Collection • Monitoring • Additional Risk Characterization • Mitigation[2] • Source Remediation[2]
Risk > $1x10^{-4}$	Response Action Needed	• Vapor Intrusion Mitigation[3] • Source Remediation[3]

[1] Estimated based on multiple lines of evidence, as established in the Vapor Intrusion Guidance.

[2] Mitigation is intended to reduce the entry of volatile chemicals from a subsurface source into building air and, as feasible, should be conducted in conjunction with source remediation. DTSC does not consider a VI mitigation system as a means of remediating the source of the subsurface contamination. However, mitigation may be used as a long-term measure for lower risk sites.

[3] Both VI mitigation and source remediation should be implemented for sites in this risk range. However, site-specific conditions (such as where the source of contamination is located off-site) may necessitate use of mitigation as the long-term measure.

No Further Action (Risk < $1x10^{-6}$; HI $\leq$ 1). The point of departure for risk management decisions for cancer risk is 1 x 10^{-6} and for noncancer health hazards is a HI of 1. If the estimated cancer risk and hazard are less than these points of departure, as indicated by multiple lines of evidence, no further action is necessary. See Section 1.5 for discussion of sites that choose to apply VI mitigation as a preemptive measure.

Risk Management Decision ($1x10^{-6}$ < Risk < $1x10^{-4}$; HI > 1). Sites with a risk or hazard from volatile chemicals in excess of the point of departure require a response action and long-term environmental care. Potential actions taken based on a risk management decision could include:

- continued soil vapor monitoring,
- continued indoor air quality monitoring,
- mitigation, and
- volatile chemical source remediation.

DTSC makes risk management decisions on a site-by-site basis with consideration of appropriate input from the project proponent. The decision takes into account both site-specific and chemical-specific data. Multiple lines of evidence, such as collection of additional site-specific data, are used to decrease the uncertainty in evaluating VI at a site. Experience has shown that much of this uncertainty may arise from spatial and temporal variability in the data set and that this uncertainty can be reduced by additional data collection. Chemical-specific information to be evaluated would include 1) toxicity endpoints and target-organs affected for noncarcinogenic chemicals; 2) whether a chemical is a known human carcinogen or a suspected carcinogen; and 3) the uncertainties associated with the derivation of the toxicity criteria. The above considerations will allow for a better-informed risk management decision process.

Mitigation and Source Remediation (Risk > $1x10^{-4}$). Mitigation and source remediation will be needed if the potential long-term risk to human health, as contributed by VI, is estimated to be above 1 x 10^{-4}. The timing of this response action will depend on whether there is an existing building or if future development will proceed before remedial goals are met. Chapters 4, 5, 6 and 7 discuss various aspects of mitigation actions to address the VI pathway. For any mitigation action conducted as part of the cleanup process, the responsible party should submit an appropriate response action decision document to DTSC for review and approval (see Chapter 5). The decision to implement a mitigation action should be based on sufficient site characterization data to evaluate potential human health risks from VI.

Vapor intrusion mitigation is intended to minimize entry of volatile chemicals from the subsurface into the indoor air of overlying buildings. Vapor intrusion mitigation is not intended to be a sole remedial alternative for a volatile chemical contaminated site. For most sites in this risk range, remediation will be required to address the subsurface source of vapor contamination. However, based on site-specific considerations, mitigation may become the long-term measure, especially where removal of volatile chemicals may not be technically feasible (such as where the volatile chemical source is located off-site).

2.3 RISK MANAGEMENT CONSIDERATIONS FOR EXISTING BUILDINGS

2.3.1 Off-Site Sources of Volatile Chemical Contamination

Soil gas plumes may be the result of off-site sources of volatile chemical contamination in soil gas or shallow groundwater. The off-site source may be part of a larger, regional contamination. The off-site source of contamination may or may not currently be under the oversight of a regulatory agency for investigation and management. If the soil gas plume originates from off-site sources, incorporating VI mitigation into the existing building may be the only viable option, especially if the off-site source is regional in nature and remediation of off-site sources is impractical or not achievable in the near future.

Migration of the off-site plume onto the site may also be a concern. While the off-site plume may not currently have adversely affected the site, the plume may pose a future VI risk. In this case, incorporating VI mitigation into existing or future buildings may be prudent. Additionally, the plume should be evaluated using appropriate plume modeling techniques and/or groundwater monitoring.

2.3.2 Ambient/Background Air Sources of Volatile Organic Compounds

For urban areas, many VOCs are ubiquitous in ambient, outdoor air. Common VOCs in ambient air include benzene, trichloroethene (TCE), and tetrachloroethene (PCE). While measured indoor air concentrations may pose a potential long-term health risk, these concentrations may also be identical to ambient levels. Therefore, source removal or VI mitigation may not reduce the indoor air concentrations of such ubiquitous volatile chemicals.

Consistent with the Vapor Intrusion Guidance, ambient/background air samples should be collected to determine if ubiquitous volatile chemicals are contributing to the measured indoor air concentrations. A sufficient number of outdoor air samples should be collected to provide a meaningful comparison between indoor air and outdoor air concentrations. This comparison should also be considered in terms of the cumulative indoor air risk associated with the target volatile chemicals. Specific risk considerations would include the exposure scenario being evaluated (e.g., residential, industrial/commercial, school-based) and the risk associated with target volatile chemicals measured in outdoor air for the appropriate exposure scenario.

In addition to collecting background air samples, evaluating the ratio between concentrations of volatile chemicals in the subsurface and concentrations of volatile chemicals in indoor air may help in distinguishing contributions from background air versus VI from the subsurface. Air quality data collected from monitoring stations within a local air management district provides secondary evidence for distinguishing VI from other sources.

Because of the high cost associated with conducting indoor air studies, sufficient numbers of samples may not be available to conduct rigorous statistical evaluations. Given such data limitations, the comparison may often be qualitative in nature and will require a risk management decision regarding the need for further action or mitigation.

2.3.3 New Building Indoor Air Sources of Volatile Chemicals

Volatile chemical concentrations measured in indoor air could originate from off-gassing of building materials rather than from VI. For example, DTSC conducted an indoor air quality investigation at a newly constructed school building overlying a TCE plume. Elevated levels of vinyl chloride (a potential degradation product of TCE) were detected in most of the classrooms and ultimately were determined to be from unidentified indoor sources.

2.3.4 Residential Sources of Volatile Organic Compounds

In addition to ambient air and building materials, other sources of VOCs indoors include consumer products (such as household cleaning materials and dry cleaned clothing). To help put these background sources of VOCs into perspective, EPA recently published a technical report evaluating measured concentrations of VOCs in the indoor air of thousands of residences in the U.S. from sources other than VI (USEPA, 2011).

2.4 RISK MANAGEMENT CONSIDERATIONS FOR FUTURE BUILDINGS

2.4.1 Re-evaluate Indoor Air Risk Using Site-Specific Soil Parameters

Additional data collection may be required 1) to better define the lateral and vertical extent of volatile chemical contamination and 2) to refine the predicted indoor air risk based on site-specific soil parameters. Site-specific soil parameters are particularly important because they can reduce the predicted indoor air risk compared to the risk estimated using screening-level default parameters. Refer to the Vapor Intrusion Guidance for further details.

2.4.2 Adjust Development Plans to Avoid Vapor Intrusion Issue

If sufficient data exists, soil gas isoconcentration contours and geologic cross-sectional diagrams may be constructed for the planned building location. If the soil gas plume is well characterized spatially, the development plans may be adjusted so that buildings are not constructed immediately over the plume, and instead are constructed a sufficient distance away from the plume, thus eliminating the VI pathway. In some cases, risk isopleths constructed from concentration data may better illustrate areas where inhalation health risks should preclude building construction or sensitive land uses.

Building designs may also be adjusted, to include intrinsically safe designs (such as podium construction) in which the ground level of a building is maintained as a well-ventilated space not intended for human occupation.

2.4.3 Evaluate Whether Monitoring Alone Would Be Sufficient

If the volatile chemical plume does not impact or only impacts a fraction of the proposed building foundation, the estimated indoor air risks may not be significant and only continued soil gas monitoring may be required. This circumstance is best evaluated by considering the site plans and layout of proposed structures together with the plume maps (for example, volatile chemical isoconcentration contours, geologic cross-sectional diagrams). Additionally, a passive VI mitigation system that can be converted to an active system may be an appropriate cautionary approach in these cases where indoor air risks are minimal.

2.4.4 Off-Site Sources of Volatile Chemical Contamination

The same off-site plume issues pertaining to existing buildings (Section 2.3.1) also apply to future buildings. If the soil gas plume is coming from off-site sources, incorporating VI mitigation as part of the building design is prudent, especially if the off-site source is regional in nature and source remediation is impractical or not achievable in the near future.

3.0 PUBLIC PARTICIPATION

Public concerns associated with VI will typically be greater than those associated with other media contamination because 1) simple avoidance techniques (such as elimination of exposure pathways) are not an option for impacts to the air people breathe and 2) involuntary exposure in one's home, workplace, or school is potentially unsettling. Hence, more extensive outreach is generally necessary for VI-impacted sites than may be needed for sites affected by other exposure pathways. Face-to-face meetings with those stakeholders who live, work, or otherwise occupy the buildings with known or potential VI issues are often necessary. On-going regular communication with affected community members and building occupants is important during all phases of a VI project, including during the selection, design, installation and O&M of a VI mitigation system.

As with any contaminated site, DTSC's *Public Participation Policy and Procedures Manual* (DTSC, 2001; revision pending) should be followed. Additionally, DTSC's *Vapor Intrusion Public Participation Advisory* provides guidance specific to VI-impacted sites.

4.0 VAPOR INTRUSION MITIGATION METHODS

DTSC recommends that VI mitigation be implemented as an interim response action until volatile chemical concentrations in soil, soil gas, or groundwater are confirmed to be at acceptable levels. The goal of a VI mitigation system is to interrupt the pathway between the source of the vapors and building occupants until remedial goals in the subsurface are met. As discussed in Section 1.2, remediation of the subsurface is the primary means by which remedial goals are achieved at a site, rather than the VI mitigation system. Nonetheless, there are instances where source removal is impracticable and the use of engineering controls would be the most feasible response action. For most sites, remediation and mitigation are complementary components of a volatile chemical response action, addressing cleanup of subsurface contamination and impacts to the human receptor, respectively. Where source removal is impracticable, the use of engineering controls may be the most feasible long-term response action (see Chapter 2). The response action decision document should clearly describe the integration of the remediation and mitigation components (see Chapter 5).

4.1 CONCEPTUAL MODEL OF VAPOR INTRUSION

The air pressure within a building is typically somewhat less than the atmospheric pressure surrounding the building. This difference in pressure is caused by thermal differences between indoor air and surrounding soils, wind and barometric changes, and stack effects of chimneys and flues. Thus, the negative pressure differential present in most buildings may cause vapor-phase contaminants to migrate from the subsurface into the structure, and it is this pathway that needs to be interrupted. Volatile chemicals can enter a building through entry points such as cracks or perforations in slabs or basement floors and walls, openings around sump pumps, elevator shafts, or where pipes and electrical wires go through the foundation.

4.2 OVERVIEW OF MITIGATION TECHNOLOGIES

Well-established techniques, developed for mitigating exposures to radon and methane, are the basis for most VI mitigation technologies. These techniques and associated guidance are appropriate for volatile chemicals because the vapors may enter a building in the same manner as radon and methane. Table 2 identifies various mitigation technologies for addressing VI into buildings as well as the specific applications, advantages, and disadvantages of each technology. Figure 3 illustrates the technologies that are suitable for existing and future buildings and appropriate for the building usage.

Because SSD and SSV systems are the most commonly used mitigation techniques (USEPA, 2008b), the VIMA emphasizes these systems over other technologies. The purpose of this emphasis is to relieve the project proponent of providing an in-depth analysis of all types of mitigation systems, and to easily select either a SSD or SSV system when mitigation is needed. However, the VIMA does not preclude other approaches (such as those described in Section 4.4) from being proposed. Depending on site-specific characteristics, one of the alternate mitigation strategies may be a better fit at an individual site, rather than a SSD or SSV system. Moreover, additional, new technologies may be developed in the future that are consistent with sustainable and modern building design and may prove to have results equal to or better than those garnered by SSD or SSV systems.

4.3 SUB-SLAB VENTING AND SUB-SLAB DEPRESSURIZATION SYSTEMS

The USEPA recommends that the model building standards and techniques for radon control in new residential buildings constructed on basement and slab-on-grade foundations include: installing a layer of permeable sub-slab material; sealing the joints, cracks, and other penetrations of slabs and foundation walls; providing a soil-gas retarder (sub-slab liner) beneath floors; and installing either a SSV or SSD system. As described further below, the distinction between the two systems is that a SSD system is designed to mitigate VI by achieving measurable, continuous sub-slab pressure reduction and a SSV system is designed to reduce or dilute sub-slab volatile chemical concentrations.

Sub-slab liners are used with both SSV and SSD systems. The sub-slab liner is an integral component of a SSV system (as described further in Section 4.3.1). DTSC considers a sub-slab liner to be a safety factor for a SSD system for instances in which the system is shutdown for repair (see Section 4.3.2). Additional discussion of sub-slab liners is provided in Section 4.4.

4.3.1 Sub-Slab Venting Systems

A SSV system is designed to function by venting sub-slab soil gases or providing a pathway to allow soil gas to migrate to the exterior of the building rather than entering a building. SSV systems function by drawing in outside air to the sub-slab area, which dilutes and reduces volatile chemical concentrations. SSV systems typically consist of a layer of venting material (sand or pea gravel) emplaced below a floor slab to allow soil gas to move laterally under natural diffusion or pressure gradients to a collection piping system for discharge to the atmosphere. SSV systems include a sub-slab liner that is installed on top of the venting layer. To the extent that the liner is intact, the sub-slab liner aids venting of sub-slab soil gas via collection pipes rather than upward into the building.

In a SSV system, vapors are directed to the edge of the foundation by perforated collection pipes that are installed in the venting layer, beneath the slab, or at the periphery of the foundation. Usually, the collection pipes are connected to a main header point that runs up through or along the inner or outer building wall and exhausts above the roofline. Installation of a vertical inlet pipe system within or next to the building allows fresh air to enter into the gravel blanket or sub-slab zone, which results in diluted or reduced volatile chemical concentrations.

Because of the extensive foundation work involved in the installation, SSV systems are generally easier to install in new construction rather than existing buildings. SSV systems may not be appropriate in areas with a high groundwater table or surface drainage problems because the venting system will not function properly if continuously saturated with water.

A SSV system may result in the air pressure below the slab being reduced somewhat compared with that of the building interior, particularly near the vent pipe intake in the venting layer and during atmospheric conditions favorable for SSV. However, there is typically no design objective or requirement in a SSV system to maintain a lower pressure of any given magnitude below the floor. Thus, if there are gaps or holes in the liner and floor, it is possible that soil gases could flow into the building whenever pressure conditions favor that flow direction. However, an effective SSV system could remain protective under these circumstances and, in general, by diluting and reducing the volatile chemical concentrations in sub-slab soil gas to a level where minor or intermittent VI does not cause volatile chemical concentrations in indoor air to exceed the indoor air quality goal.

SSV systems are monitored by measuring volatile chemical concentrations in sub-slab soil gas, or by measuring concentrations of indoor air. Thus, a sampling port within the vertical collection pipe or in the horizontal vent pipes below the floor should be included as part of the SSV design. The sampling point should be fitted with a non-restricting, screened rain guard to prevent precipitation and debris from entering the piping system. Measuring volatile chemical concentrations in sub-slab soil gas will verify that the SSV system is providing adequate dilution or removal of sub-slab volatile chemicals such that VI is not occurring at a significant level. To demonstrate SSV effectiveness using sub-slab soil gas testing, a reasonable goal may be to reduce volatile chemical concentrations in sub-slab soil gas to less than 20 times the acceptable indoor air level, based on an attenuation coefficient of 0.05 (DTSC, 2011) between sub-slab soil gas and indoor air in the un-mitigated building.

A different attenuation factor, higher or lower, may be used providing it is justified by supporting data, such as the use of tracer gases or marker chemicals such as radon.

SSV systems may result in less depressurization and lower air flow rates than SSD systems. In most buildings, SSV systems are unlikely to perform as well as SSD systems, and therefore may not be an appropriate technology in areas with high concentrations of contaminant vapors. However, in areas with lower concentrations of contaminant vapors, a SSV system will provide adequate protection and will often be the preferred technology.

SSV systems may be either passive or active (installed fan). Passive SSV systems rely on natural thermal and wind effects to withdraw soil gases from the sub-slab venting layer to dilute and reduce volatile chemical concentrations to a protective level. Active SSV systems use a fan to achieve the same purpose by: 1) withdrawing and venting soil gases; 2) actively blowing ambient air into the venting layer beneath a building (referred to as sub-slab pressurization); or 3) other engineering variations such as including wind-driven fans on riser pipes. SSV systems are commonly used in new construction sites as a preemptive measure against VI (see Section 1.5). All passive SSV systems should be built so that upgrade to an active SSV system is possible at a later date with minimum effort. Prior to construction, criteria should be developed that clearly establish when SSV systems need to be upgraded. These criteria typically are based on volatile chemical concentrations measured in sub-slab soil gas or indoor air at concentrations above project goals.

4.3.2 Sub-Slab Depressurization Systems

SSD systems are applicable for slab-on-grade building construction. For buildings with crawl spaces, a sub-membrane depressurization (SMD) system is more appropriate than a SSD system, as described below in Section 4.4. A SSD system is designed to function by continuously creating a lower pressure directly underneath a building floor relative to the pressure within a building. The resulting sub-slab negative pressure inhibits soil gases from flowing into the building, thus reducing volatile chemical entry into the building. Volatile chemicals caught in this negative pressure field are collected and piped to an ambient air discharge point. The depressurization under the slab is typically accomplished with a motorized blower. The blower draws air from the soil beneath a building and discharges it to the atmosphere though a series of collection and discharge pipes. *Model Standards and Techniques for Control of Radon in New Residential Buildings* (USEPA, 1994a) defines SSD technology as "a system designed to achieve lower sub-slab air pressure relative to indoor air pressure by use of a fan-powered vent drawing air from beneath the slab."

In most cases, a sub-slab liner is an appropriate, redundant feature for the conventional SSD system. To the extent that the liner is intact, it would provide some protection in the event that the blower fails. Additionally, the liner may increase the efficiency of the system so that a smaller fan is required. Some SSD systems may not require a liner (such as aerated floor systems). In this case, the project proponent should discuss the proposed design with DTSC, and a site-specific determination made on a case-by-case basis.

The sustained effectiveness of SSD systems can be adequately evaluated by monitoring the blower operation and the reduced pressure beneath the floor, as described in more detail in Chapter 7. Thus, regardless of the mechanism for creating the reduced pressure, a SSD system can be effectively monitored through routine pressure monitoring once an adequate demonstration of the mitigation system effectiveness has been established. The pressure monitoring requirements for a SSD system are generally easier to implement routinely compared to monitoring volatile chemical concentrations in a SSV system.

A SSD system has some of the attributes of a SSV system, in that it may also reduce volatile chemical concentrations in sub-slab soil gas through venting. However, the magnitude of volatile chemical concentration reductions in sub-slab soil gas are less critical than for SSV systems, because the SSD system is designed to mitigate VI by maintaining a lower pressure below the building floor.

In existing structures, active SSD systems entail drilling or cutting one or more holes in the existing slab, removing a quantity of soil from beneath the slab to create an open hole or suction pit, and placing vertical suction pipes into the holes. The suction pipes are manifolded together and routed to the fan and discharged so that the soil gas can be drawn from just beneath the slab. An operating SSD system will induce indoor air to flow down into the subsurface through entry points such as cracks and openings. Soil gases from beneath the slab are collected and vented to the atmosphere at a height well above the outdoor breathing zone and away from windows and air supply intakes. More details about active SSD systems can be found in various USEPA guidance documents on radon, and in ASTM International (ASTM) guidance documents (ASTM, 2007ab).

4.4 ADDITIONS AND ALTERNATIVES TO SUB-SLAB VENTING AND SUB-SLAB DEPRESSURIZATION SYSTEMS

Other remedies in addition to, or as alternatives to, SSD and SSV systems are available to address site-specific conditions. A project proponent may propose an alternative technology for evaluation by DTSC. The selected alternative technology should achieve a balance between indoor air quality issues and compliance with energy efficiency regulations (Cal. Code Regs., tit. 24, part 6). The project proponent may also propose technologies not specifically described in VIMA for DTSC's consideration. VIMA encourages innovation and the implementation of new, more effective and more sustainable approaches to VI mitigation, as they become available.

Sealing Cracks and Openings. Cracks and openings in the building foundation are the primary routes of vapor entry, rather than diffusion through the concrete slab itself. An exception would be very thin slabs or sites where soil gas concentrations are very high. Thus, an important first step in preventing VI is to seal cracks in the floors and walls of a building, as well as gaps around utilities, floor drains, dry utilities, sumps, elevator shafts, and other piping systems. Sealing cracks and openings should not be considered as a standalone action, but should be completed as a preliminary step in conjunction with other mitigation strategies.

Sub-slab Liners (Passive Membranes or Vapor Barriers). Sub-slab liners are materials or structures installed below a building to block the entry of vapors. These liners have traditionally been used to prevent moisture from accumulating behind drywall walls, thus giving rise to the name “vapor barrier.” Sub-slab liners ideally cause soil gas that would otherwise enter the building to migrate laterally beyond the building footprint. However, in practice, sub-slab liners are not able to completely eliminate VI due to the likelihood of punctures, perforations, tears, and incomplete seals. Thus, sub-slab liners by themselves are not an acceptable VI mitigation system to DTSC for indoor air risks greater than or equal to 1×10^{-6} and a HI greater than or equal to 1 (see Chapter 2 for further discussion of the risk management framework). Liners should be used in combination with a SSV, SSD, or SMD system.

Submembrane Depressurization (SMD). For a SMD system, a membrane (liner) is used as a surrogate for a slab to allow depressurization. A membrane covers the exposed dirt surface of a crawl space while the depressurization system withdraws soil gas from beneath the membrane and prevents its intrusion into the overlying space.

The edges of the foundation wall must be well sealed, and the membrane must be loose enough to prevent tearing under stress. Periodic inspection is required because membranes can be easily damaged or lose their seals at the edges. SMD is effective for retrofitting buildings with crawl spaces.

Building Pressurization. Building pressurization involves adjusting the building heating, venting, and air conditioning (HVAC) systems or installing a new system to maintain a positive pressure indoors relative to the sub-slab area. This approach is more commonly used for commercial buildings and can be cost effective if the existing HVAC system already maintains a positive pressure. Having to increase the pressure will result in larger energy costs, particularly if significant heating and cooling is required. Positive pressurization of buildings is practicable only when the building is relatively tight, with few doors or other openings. Therefore, warehouses with large bay doors are not candidates for positive pressurization. DTSC will consider HVAC alteration as a response action for commercial/industrial buildings on a case-by-case basis, particularly if the HVAC system for an existing building was not operating pursuant to current building codes and energy efficient codes and/or requirements (Cal. Code Regs., tit. 24, part 6). DTSC does not consider building pressurization to be an appropriate mitigation technology for residential structures.

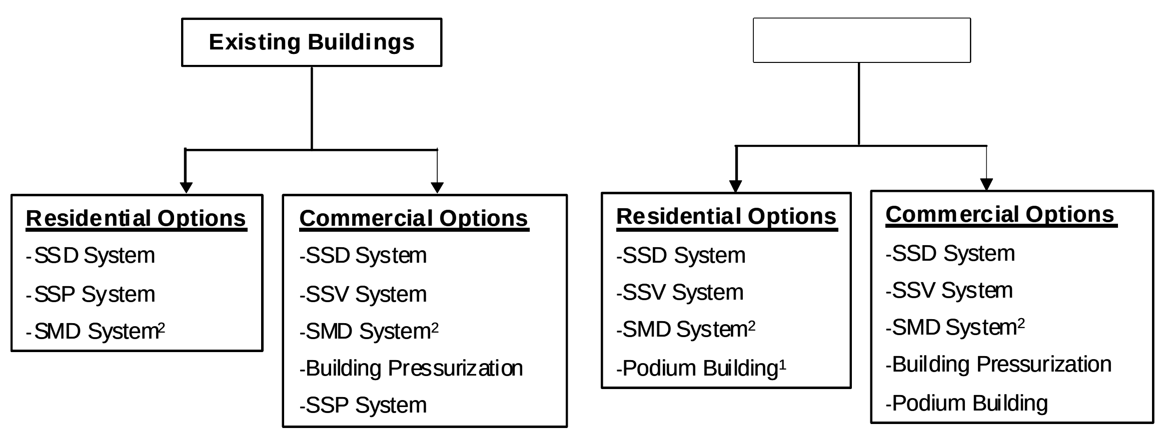
Indoor Air Treatment. This method directs air within the structure to air pollution control equipment to remove toxic air contaminants from the building interior rather than preventing entry into a building. DTSC is critical of this method for several reasons. Indoor treatment is not a proven, developed technology available for widespread application to buildings. Other drawbacks to this method are that it encourages collection of contaminant vapors within the structure and is dependent on uninterrupted performance of the treatment system to protect building occupants. DTSC will consider this technology in some cases, but only if project goals cannot be achieved by engineering controls described elsewhere in this Advisory.

Variations on SSD Systems. The systems described below are all variations of SSD systems. DTSC will consider site-specific variations to the design in order to provide for the most effective system for the site.

- Aerated floor systems are typically constructed using plastic forms over which concrete is poured.
- Block-wall suction systems involve removing vapors that accumulate in basement walls constructed of hollow blocks.
- Drain-tile suction systems apply suction to existing water drainage systems that circle a building in order to remove vapors. This requires a separate dewatering system below the venting system to allow vapors or gases to escape and not be trapped and possibly pressurized due to water in the pipes or vents.
- Sub-slab pressurization (SSP) systems are a specific type of SSV system, except that fans are used to push air into the venting layer below the slab, instead of pulling the air out. This technology may be particularly effective in higher permeability soils. However, active injection of air under a building (to

enhance venting) is not recommended without having an engineering design. SSP systems may force vapors into a building by creating elevated subsurface pressures or force vapors into unprotected neighboring structures. Care should be taken to seal cracks and openings when utilizing a sub-slab pressurization system. Permitting requirements may apply to these systems in some jurisdictions.

Podium-Style Buildings. The risk from VI may be greatly reduced by a building design that utilizes an open air first floor, stilts, or an appropriately ventilated first floor space. An example of such a building design is a well ventilated ground level parking structure. However, all potential vapor conduits to upper floors of the building (particularly utility lines, elevator shafts, and ventilation systems) must be engineered and sealed in a manner that reduces the risk of VI. Such provisions may include construction of the elevator on an exterior wall of the building (rather than having an interior, central entrance), sealing the base of the elevator, possible venting, and increased ventilation of the elevator. If used as an enclosed parking area, additional consideration is needed to achieve ventilation flow rates required to ensure acceptable levels of carbon monoxide and volatile chemical concentration levels. In general, DTSC considers podium-style buildings inappropriate for use with single-family dwellings because of concern that individual home owners may alter or convert their garages to livable space.



Notes:
[1] In general, appropriate for multi-family dwellings only
[2] For buildings with crawl space
SMD is submembrane depressurization
SSD is sub-slab depressurization
SSP is sub-slab pressurization
SSV is sub-slab venting

Figure 3
Vapor Intrusion
Mitigation Technologies

Table 2. Overview of Selected Vapor Intrusion Mitigation Technologies
(Modified from ITRC (2007))

TECHNOLOGY	PPLICATION	DVANTAGES	ISADVANTAGES
Sub-slab Depressurization (SSD) A	• New and existing (without liner) slab-on-grade structures • Sumps, drain tiles, and block wall foundations may also be depressurized if present A	• Successful track record of performance • Adaptable technology, applicable to a wide variety of site conditions and geology • Simple gauges show whether the system is working • Works well for conditioned crawl spaces with concrete slabs D	• Requires periodic maintenance • Building-specific conditions may limit options for suction pit, riser pipe, and blower locations • Long-term energy and maintenance costs • May not be feasible for large, commercial buildings • More expensive to retrofit existing structures (hence it works best for new construction)
Sub-Slab Venting (SSV)	• New slab-on-grade construction • Low soil gas flux sites • Should be convertible to active system if necessary	• Successful track record of performance • Passive systems avoid the long-term O&M costs of systems requiring electricity to operate a fan or blower	• Not as effective as SSD – should only be used when risk is moderately elevated • Ambient temperatures and winds can adversely impact success • Not suitable for existing structures unless very modest concentration reductions are required • Upgrade of passive SSV systems to active SSV systems likely to be necessary for new structures when large reductions in concentrations are required
Submembrane Depressurization (SMD)	• New and existing buildings with crawl spaces	• Similar to SSD • Ideal for enclosed crawl spaces without concrete slabs • Appropriate to retrofit existing buildings with crawl spaces	• Similar to SSD • Liners can be easily damaged and must be well-sealed at edges to prevent leaks • System needs to be periodically inspected to confirm leaks are not present

Table 2 (Continued)

TECHNOLOGY	PPLICATION	DVANTAGES	ISADVANTAGES
Sub-Slab Pressurization (SSP)	• New and existing slab on grade structures	• May be more efficient in high permeability soils	• More energy intensive than routine SSV and SSD systems • May not be appropriate for low permeability soils
Building A Pressurization	• Large commercial structures, new and existing A	• Can be applied equally well to both new and existing structures D	• Generally more costly than other techniques • Regular maintenance and air balancing needed to maintain consistent, positive pressure • Will require extensive reporting requirements to ensure appropriate building pressure is maintained • Increased energy costs
Indoor Air Treatment	• Specialized cases only	• Results in physical removal and disposal of the air contaminant, not simple redirection	• Not appropriate for widespread application • Less effective than other control methods (when applicable) • Maintenance-intensive and costly to install and operate • System leaks, should they occur, may result in higher exposures than without control • Building owners and occupants may have heightened concern of indoor air contamination • Temporary or permanent relocation may become necessary
Podium-style Building	• New construction, industrial & commercial, multifamily residences	• Low capital costs	• Needs to be monitored and enforced
Aerated Floor Systems	• New construction	• Low capital cost • Can be tested and monitored • Open void space works as a venting feature	• Newer technology unproven within the USA
Land Use Covenants	• New and existing construction	• Low capital cost	• Needs to be monitored and enforced

5.0 EVALUATION OF VAPOR INTRUSION MITIGATION APPROACHES

This chapter describes the process for evaluating the feasibility of VI mitigation approaches and determining which approach (or combination of approaches) is best suited for a particular site. Because VI mitigation is part of a volatile chemical response action, its selection is based on a screening and detailed analysis of alternatives. Whenever possible, the evaluation of VI mitigation approaches should be integrated with the evaluation of remedies to address the subsurface vapor sources.

5.1 SCREENING VAPOR INTRUSION MITIGATION ALTERNATIVES

Development and screening of mitigation alternatives should begin during the investigation phase, or soon thereafter, when response actions have been determined to be necessary. Chapter 4 presents the technologies that are currently available for VI mitigation. The project proponent is encouraged to consider other new, more effective and more sustainable approaches to VI mitigation as they become available. The scope of the screening evaluation for VI mitigation alternatives should reflect site-specific circumstances. Some alternatives may not be screened because they are not appropriate for site conditions or are not feasible because of the planned or potential land use (see considerations for each technology described in Chapter 4). For example, only buildings with crawl space would screen an SMD system.

5.2 DETAILED ANALYSIS OF MITIGATION ALTERNATIVES

The detailed evaluation of VI mitigation approaches involves a comparison of each approach or combination of approaches to a set of evaluation criteria. The criteria[2] for evaluating VI mitigation approaches include:

Threshold Criteria

1) Overall protection of human health and the environment,
2) Compliance with federal/state/local requirements,

Balancing Criteria

3) Long-term effectiveness and permanence,
4) Reduction of toxicity, mobility or volume through treatment,
5) Short-term effectiveness,
6) Implementability based on technical and administrative feasibility,
7) Cost,

Modifying Criteria

8) State and local agency acceptance, and
9) Community acceptance.

The detailed analysis results provide a basis for identifying a preferred mitigation approach and documenting the rationale behind the decision. General or classical engineering evaluation criteria for the detailed evaluation of alternatives have been established for hazardous substance release sites in guidance and regulations (see

[2] Only the effectiveness, implementability, and cost criteria apply to the DTSC Removal Action Workplan process.

Table 3). In addition, there are technology-based considerations which should be used to determine if approaches are feasible and can be carried through to an overall final response action decision that is protective and implementable. Additional data which may be needed to fully evaluate VI include environmental justice issues, ambient air quality, building HVAC operation, and local land use zoning.

Table 3. State and Federal Guidelines for Alternatives Evaluation

LAW	PROCESS	DESCRIPTION	SUGGESTED REFERENCE(S)
HSAA	Remedial Action Plan (RAP)	Process for developing, screening, and detailed evaluation of alternative remedial actions for sites. Response action selection document under HSC §25356.1.	DTSC, 1995
	Removal Action Workplan (RAW)	Prepared when a proposed, non-emergency removal action or a remedial action is projected to cost less than $2,000,000. Response action selection document under HSC §25356.1.	DTSC, 1993, 1998
CERCLA	Feasibility Study (FS)	Process for the development, screening, and detailed evaluation of alternative remedial actions for sites. A FS is not required for the RAW process; however, the RAW should evaluate effectiveness, implementability, and cost of various removal alternatives.	USEPA, 1988, 1999
	Engineering Evaluation/ Cost Analysis (EE/CA)	Analogous to, but more streamlined than, the FS. Identifies the objectives of the removal action and analyzes the effectiveness, implementability, and cost of various alternatives that may satisfy these objectives.	USEPA, 1993
RCRA or HWCL	Corrective Measures Study (CMS)	Mechanism used by the corrective action process to identify, develop, and evaluate potential remedial alternatives.	USEPA, 1991, 1994b, 1997
HSAA, HWCL, RCRA, CERCLA	Interim Measures (IM) or Interim Actions	Actions to control and/or eliminate releases of hazardous waste and/or hazardous constituents from a facility prior to the implementation of a final corrective measure or response action.	

Notes:
CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act
HSAA – Hazardous Substance Account Act
HWCL – Hazardous Waste Control Law
RCRA – Resource Conservation and Recovery Act

The project proponent should consider site-specific conditions (such as existing versus future building, building type, building use, receptor type, and volatile chemical concentrations) when selecting the most appropriate technology to mitigate the VI pathway. Table 4 provides a qualitative assessment of factors that should be considered in the selection process. As indicated by the table and described in Chapter 4, some technologies are not appropriate for mitigating a higher degree of risk or hazard. For instance, use of institutional controls as the mitigation approach might only be considered for a low degree of risk or hazard. In addition, depending on the degree of risk or hazard posed by the VI pathway, some technologies are better suited to certain building uses. As an example, DTSC generally recommends use of podium-style buildings for multi-family residences rather than single-family residences. A given mitigation technology may have greater monitoring needs (because it is a less effective technology and/or because of the system design) which leads to higher long-term costs. For example, because SSV system performance is evaluated through chemical analyses (e.g., sub-slab vapor), the monitoring frequency and costs for this technology are relatively high when compared to technologies that have multiple performance metrics (such as SSD systems which are evaluated primarily through pressure measurements). The table also illustrates that some technologies have relatively higher capital costs but lower long-term costs than other technologies (and vice versa).

The following elements should be included with the detailed evaluation of the mitigation alternative.

- Establishment of site-specific performance objectives for the VI mitigation system;
- Recordation of land use covenants;
- Recognition of long-term responsibilities in maintaining financial assurance and compliance with the five-year review requirement;
- Identification of applicable federal/state/local requirements; and
- Evaluation of the mitigation alternatives and the no action alternative against the applicable criteria.

5.3 DOCUMENTATION OF DETAILED EVALUATION RESULTS

Once the evaluation is complete, the project proponent should present the detailed analysis of VI mitigation approaches in an appropriate report (e.g., Feasibility Study, Corrective Measures Study Report). If the report is approved by the appropriate agencies, selection of the mitigation approach should be presented in a decision document such as a Proposed Plan, Record of Decision, Removal Action Workplan, Remedial Action Plan or Statement of Basis. The decision document generally outlines the conceptual plan for remediating the vapor source and mitigating VI. Decision documents are typically released for public comment and, if needed, responses to community, stakeholder, property owner, and responsible party comments are prepared.

After the public comment period and regulatory agency approval of the decision document, the project proponent typically prepares a detailed design of the mitigation approach. The design outlines all specific elements of designing and implementing the mitigation approach. These specific elements include not only the mechanical, electrical and structural elements, but also O&M, monitoring and reporting, financial assurance, implementation schedule, five-year review schedule, and the identification of who is responsible for conducting these activities. Chapters 6 and 7 provide further discussion of the design and implementation of the mitigation approach.

5.4 CALIFORNIA ENVIRONMENTAL QUALITY ACT

Cleanups for VI must meet all applicable local, state and federal requirements including the California Environmental Quality Act (CEQA). CEQA (Pub. Resources Code, sec. 21000 et seq.) requires public agencies carrying out or approving a project to conduct an environmental analysis to determine if project impacts could have a significant effect on the environment. Public agencies must eliminate or reduce the significant environmental impacts of their decisions whenever it is feasible to do so.

Proposed projects for which DTSC has discretionary decision-making authority are subject to CEQA if they potentially impact the environment. Examples of approval actions which require CEQA review and documentation include: remedial action plans, interim measures, removal action workplans, and corrective actions. As shown by these examples, certain steps described in the VIMA are subject to CEQA. For further information, DTSC's CEQA-related policies and procedures are available on the DTSC internet site.

Table 4. Qualitative Comparison of Selected Vapor Intrusion Mitigation Technologies

Mitigation Technology[1]	Typical Application	Degree of Risk or Hazard Being Mitigated[2]	Monitoring During First Year of VI mitigation Operation		Monitoring During Long-Term VI mitigation Operation		Relative Cost		
			Operational Parameters[3]	Chemical Analyses	Operational Parameters[3]	Chemical Analyses	Capital	O&M	Monitoring
Institutional Control	R, C/I	L	n/a	M	n/a	M	n/a	L	M
Membrane Only	P	VL	n/a	M	n/a	M	L	n/a	M
SSV System	C/I, R	L	n/a	M	n/a	L	L – M	L	L – M
	C/I, R	M				M			M
SSD System	C/I, R	L	M – H	L	M	L	M – H	L – M	L
	C/I, R	M, H		M					
SMD System	C/I, R	L	M – H	M	M	L	M – H	L – M	L
	C/I	M, H							
Building Pressurization	C/I	L	M	L – M	M	L	L	M – H	L
	C/I	M, H	M – H	M		L – M			L – M
Indoor Air Treatment[4]	C/I	L	n/a	L – M	n/a	L – M	L – H	L – H	L – M
	C/I	M, H		M – H		M			M
Podium Building	R[5], C/I	L, M, H	n/a	L	n/a	L	n/a	L	L

Notes:
1 See discussion of these technologies in Chapter 4.
2 Estimated based on multiple lines of evidence as established in the Vapor Intrusion Guidance.
3 e.g., pressure differential, flow rate
4 As discussed in Chapter 4, DTSC will consider for special cases, but only if project goals cannot be achieved by other engineering controls.
5 In general, DTSC recommends use of podium buildings for multi-family residences. See Chapter 4.

C/I commercial/industrial
H high
L low
M moderate
n/a not applicable
P preemptive applications (See Section 1.5)
R residential (single or multi-family dwelling)

SMD sub-membrane depressurization
SSD sub-slab depressurization
SSV sub-slab venting
VI mitigation VI mitigation
VL very low

6.0 VAPOR INTRUSION MITIGATION SYSTEM DESIGN

This chapter focuses on topics related to the general design of VI mitigation systems. It begins with a discussion of design considerations for VI mitigation systems and progresses to recommended design criteria for SSD and SSV systems followed by construction quality assurance/quality control (QA/QC) testing. The chapter closes with a section outlining the preferred content of design documents for a VI mitigation system.

6.1 DESIGN CONSIDERATIONS

This section identifies considerations which may impact, or should be included as part of, the VI mitigation system design. These considerations are appropriate for any proposed mitigation approach unless indicated as being specific to SSD and SSV systems. Appendix A identifies example design considerations for SSD and SSV systems. Appendix B provides additional information regarding other design considerations that DTSC or a local agency might require.

6.1.1 Overall Building Design

Whenever possible, the concerns and needs of current and future building occupants should be considered during the building design process. For existing buildings, building owners and occupants should be asked their opinion about where blowers and piping should be located, what level of blower noise is acceptable, how readable different system-operation gauges and meters are, and what quality of construction craftsmanship is satisfactory. Issues regarding piping routes, blower location or vibration, and noise concerns should also be discussed with building owners and occupants. For example, if the mitigation contractor is considering an attic location for a blower, owners and tenants should be questioned about the current and near-future use of that space. For existing buildings, when there are multiple mitigation options, the advantages and disadvantages associated with each option should be presented to the building owner and occupants, along with an explanation as to what alternative is preferred, and why.

New Buildings. VI mitigation components should be integrated into the overall building design process for new buildings. For example, varying the location of elevator shafts, basements, utility conduits, and even the footprint of the building itself might help reduce the risk of VI. Multiple subcontractors working independently during new building construction may not be aware of the requirements associated with installation of a VI mitigation system, and may unwittingly jeopardize the integrity of the system. The VI mitigation contractor is responsible for working with the prime contractor to ensure that subcontractors are aware of the VI mitigation system and that inadvertent damage to the system is avoided.

Existing Buildings. VI mitigation systems installed in residential buildings should be designed, installed, and operated in a manner that minimizes noise and vibration. This is a particular concern for regenerative blowers and/or units installed in an attic. Special insulation and/or mounting hardware may be necessary in such applications. Blower units should be located as far from sleeping areas as possible and should be readily accessible for inspection. For building modifications, the responsible party should contact the local municipal building department to determine if any permits are required. Aesthetic impacts (e.g., building appearance) should be considered in the design process.

6.1.2 Monitoring Devices and Alarms for Sub-Slab Depressurization Systems

A SSD system should have some sort of alarm or monitoring device so that building occupants are informed immediately if the system fails. This can be accomplished by installing an in-line pressure gauge or manometer on the SSD system. The gauge or manometer should have clearly marked line(s) showing minimum acceptable vacuum levels. Where appropriate or feasible, in addition to a manometer or gauge, visible and audible alarms should be considered in order to indicate loss of system vacuum or power. In all cases, clear instructions (with the name and phone number of a person to be contacted in such an event) should be placed in a visible location, such as near the gauge or manometer.

6.1.3 Back Drafting and Short Circuiting

The operation of a SSD system may, in some cases, increase the depressurization level of a building to the extent that “back drafting” could occur. Back drafting in association with oil/gas furnaces, wood stoves, and fireplaces means that the appliance is sending smoke or air back into a room, rather than venting the air to the outside. Back drafting can theoretically occur if negative pressures within a building are stronger than the density differential which drives gases associated with combustion appliances up a chimney. In such cases, potentially deadly combustion gases, such as carbon monoxide, could be re-circulated into the building. The *Guide for Assessing Depressurization-Induced Backdrafting* and *Spillage from Vented Combustion Appliances* (ASTM, 1998) may be used as guidance for determining back drafting conditions. If a back drafting potential is identified, the SSD system should not be installed or operated until a qualified HVAC contractor corrects drafting problems. In addition to improvements in appliances and flues, make-up air can be ducted from the outside to provide for combustion and drafting. A carbon monoxide detector should be considered for any home where a SSD system is installed where back drafting is a possibility. Effective July 2, 2011, California law requires carbon monoxide detectors in most residential dwellings.

The presence of a sump in a basement or interior perimeter french drains may ”short circuit” the establishment of a sub-slab negative pressure field. In such cases, an air tight cover should be installed over the sump. If a sump pump is present, the cover should be equipped with appropriate fittings or grommets to ensure an air tight seal around piping and wiring, and the cover itself should be fitted with a gasket to ensure an air-tight seal to the slab while facilitating easy access to the pump (Orange County Fire Authority, Planning, and Development Services, 2008).

6.1.4 Integration of Mitigation and Subsurface Remediation Systems

Consideration should be given to the coordination between site remediation efforts and design of the VI mitigation system, including potential conflicting needs, infrastructure needs, and project schedules for the mitigation and remediation systems.

For existing buildings, any nearby active groundwater, soil gas, or soil remediation system has the potential for soil vapor concentrations to negatively impact indoor air, especially during the startup phase. Chemical oxidation, air sparging, bioremediation, hydrofracturing, bioventing, and other remedial technologies may initially mobilize or elevate concentrations of contaminants in the subsurface, or result in the generation of potentially volatile breakdown products previously not monitored in the building indoor air. These effects should be identified and controlled to prevent potential impacts to indoor air. The frequency of indoor air monitoring and soil gas monitoring may need to be increased during the startup phase of nearby active source remediation.

A perimeter soil gas monitoring system may be needed to evaluate the potential for volatile chemicals to migrate onto, or off of, the site in question and potentially impact additional structures. The soil gas monitoring system should be consistent with the site remediation/characterization goals and the Vapor Intrusion Guidance.

6.1.5 Incidental Removal Effects of Sub-Slab Depressurization Systems

The design objective of a VI mitigation system is to reduce to acceptable levels the risks posed by soil vapors infiltrating the building. Although SSD systems may have some incidental volatile chemical removal effects and benefits, these effects and benefits are minimal and will not have an appreciable impact on site contaminant levels. Thus, installation of a SSD system should not be considered to be equivalent to installation of a soil vapor extraction system. In most cases, remediation of soil, soil gas, and/or groundwater should occur independent of the VI mitigation system.

6.1.6 Safety and Environmental Hazards

Examples of safety and environmental hazards associated with a system design and that may need to be addressed include the following:

Proximity of Building Occupants During System Installation. For existing occupied structures, mitigation system installation will likely be conducted in close proximity to building occupants. Thus, safety concerns should be a priority. Attempts should be made to minimize physical hazards, noise, dust, and other inconveniences to occupants.

Concentrations Above Lower Explosive Limit. For sites where subsurface concentrations are above the lower explosive limit (LEL) of any chemical and a subsurface gas pressure of one pound per square inch or more is present, the site should be carefully evaluated. A deep well pressure relief system or other improvements, which reduce concentrations and pressures to acceptable levels, should be considered in addition to the building mitigation system. Mitigation of the elevated gas pressures at these sites may be required as a condition of site approval. Additional guidance may be provided in DTSC's *Advisory on Methane Assessment and Common Remedies at School Sites*.

Environmental Hazards. Other potential environmental hazards at the site or within existing structures should be identified and mitigated as part of the design considerations. The presence of other environmental hazards may delay construction activities until the hazard is adequately addressed or the appropriate safeguards are in place. Depending upon the age of the structure, lead or asbestos may be a concern. Generally construction prior to 1980 may have asbestos while construction prior to 1990 may have lead-based paint. Vermin and molds may also be a cause for concern due to potential health impacts from dust disturbance during construction.

6.1.7 Existing Buildings

Design of a VI mitigation system for existing buildings has the following additional considerations.

Building Foundation. An inspection of the building foundation should be conducted to identify all potential entry routes for volatile chemical-contaminated soil gases. Examples of potential entry points include cracks in concrete walls or slabs, gaps in fieldstone walls, construction joints between walls and slabs, annulus space around utility pipes, elevator shafts, and open sumps. Potential entry points should be surveyed with a portable photoionization detector or flame ionization detector. It is often possible to find elevated concentrations of select chemicals at particular points where VI is occurring.

Possible Entry Points. All possible entry routes should be sealed off, as feasible, to prevent volatile chemical entry. If a SSD system is installed, sealing entry routes will enhance the sub-slab negative pressure field. Sealing/caulking materials should not contain volatile chemicals.

Sub-Slab Permeability and Flow Characteristics. The air flow characteristics of the material(s) beneath the slab should be quantitatively determined by diagnostic testing. This is an important step in the SSD design process, and should always be performed prior to the design and installation of a SSD system. The objective of diagnostic testing is to investigate and evaluate the development of a negative pressure field via the induced movement of soil gases beneath the slab. Appendix C provides additional details regarding diagnostic testing.

Residential Homes. For existing residential homes, it may be appropriate to install a relatively standard mitigation system without building-specific designs or pre-mitigation diagnostic tests in order to expedite installation due to risk considerations. Using this 'standard design' approach allows systems to be installed more quickly, which may be important at larger sites with a number of homes requiring mitigation. However, post-mitigation testing will be required to verify that the standard design is adequate for a given home.

Future Inspections. Accommodation and provision for future building and mitigation system inspection needs should be included in the system design as well as management plans.

6.1.8 Other Design Considerations

Other design considerations include the following:

Depth to Water. The responsible party should have ascertained the depth to groundwater during site investigations. In general, the groundwater table should be at a sufficient distance below the building slab to ensure that the water table does not impede the effectiveness of a SSD or SSV system. Seasonal changes in groundwater elevation should be considered when evaluating the feasibility of a SSD or SSV system.

Labeling. The design should include specifications for prominent labeling of the system. Labels should include the purpose of the system, safety warnings, and instructions for keeping piping clear and unblocked. Labels should also include the name, address and telephone number of the entity to contact for questions and repairs. Labels should be printed in English as well as other languages as necessary. See Appendix B (item 6) for further suggestions regarding system labeling.

6.2 CONSTRUCTION QUALITY ASSURANCE / QUALITY CONTROL TESTING

Installation of a VI mitigation system should also include construction QA/QC testing of various components of the system. Typical QA/QC tests include the following:

Liner System. The responsible party should conduct a smoke test of the liner system, as recommended by the liner manufacturer, to ensure no leaks exist at the time of installation. Where leaks are identified, appropriate repairs should be undertaken and smoke testing should be repeated until no leaks are detected.

Proper Function. Testing should be conducted to verify that installed blowers, gauges, alarms, and other system components are functioning properly.

Compliance with Performance Measures. Air quality sampling[3] and/or pressure measurements should be collected to confirm compliance with the performance measures for the system (see Section 7.2.1). Generally this confirmatory sampling should occur about four weeks after system startup. Subsequent sampling should be conducted during the potentially “worst case” months of January/February and June/July (for most locations in California).

Model Home. For proposed future residential developments where the human health risks have been identified as greater than $1x10^{-4}$, a model home could be constructed at

[3] An alternative to indoor air sampling may be considered. One option is the use of slotted piping above the liner (but below the foundation) with sampling port(s) accessible on the outside of the building for baseline and compliance testing. However, this approach should be used cautiously (see further discussion in Section 7.2.3).

one or more locations of the highest potential VI concentration, within proposed development area(s), for the purpose of testing and verifying adequate VI mitigation. QA/QC testing should be conducted as described above. If possible, indoor air sampling should occur prior to the installation of carpeting or other construction features which may contribute to background volatile chemical concentrations.

6.3 DESIGN DOCUMENTS

The responsible party should submit a VI mitigation system design to DTSC for review and approval The design document can be submitted as a single or multiple documents depending on project-specific considerations and process.

6.3.1 Design Document Content

The design document should include the following recommended components, not necessarily in the listed order. The actual content of the design document is a project-specific decision.

Introduction. Identify the project, the purpose of the document, and the regulatory-basis for the VI mitigation system.

Project Background. Identify the rationale for VI mitigation, current and future property land use considerations, volatile chemicals of concern, and other general project considerations. If appropriate, this section should also indicate how the VI mitigation system is integrated with soil, soil gas, and/or groundwater remediation efforts.

Site Conditions Summary. Present the CSM and summarize:

- site geology
- site hydrogeology with emphasis on shallow groundwater in wet and dry seasons
- previous groundwater, soil, soil gas, and indoor air sampling efforts
- volatile chemicals of concern with maximum detected soil gas concentrations that would potentially impact indoor air quality
- remediation efforts and cleanup goals
- potential remediation treatment/degradation by-products
- ambient air quality considerations including predictive point source dispersion modeling or sampling
- estimation of the degree of indoor air impacts (such as Johnson and Ettinger modeling results)
- public participation efforts

This section may reference previous documents. However, an overview of the pertinent information should be provided along with references to other documents.

Existing Building Design Report. For existing buildings, an initial design report detailing the inspection of the building foundation and diagnostic tests should be prepared and submitted with the VI mitigation design document. This report should contain the following elements:

- description and diagram of the building foundation
- methods used in diagnostic testing
- results of the diagnostic tests
- existing HVAC system design and operating parameters

See Section 6.1.7 for more testing recommendations for existing buildings.

Operation and Maintenance Plan. The design document should include an O&M Plan identifying the mitigation goals and objectives, performance measures, and contingencies. The plan should identify how the goals and objectives will be monitored and tested, and may identify general institutional control requirements and/or use restrictions (such as prohibited construction and restricted building modifications). Additional O&M requirements include implementation mechanisms, and responsibilities for tasks and final obligations. See Section 7.2 for a detailed discussion of the O&M Plan content.

Design Basis. Identify the design assumptions and criteria to be met by the VI mitigation system.

Construction Methods. Identify the construction methods to be used once the design has been approved, including:

- construction specifications
- minimum material specifications
- installation procedures
- construction QC procedures
- post-installation testing procedures

Design Calculations and Drawings. Provide the design calculations and drawings for the VI mitigation system.

Conceptual Drawings. Provide conceptual drawings indicating building locations, prescribed building envelopes, streets, driveways, hardscape areas, utility easements, and other infrastructure considerations.

Vapor Intrusion Mitigation Approach. Provide a detailed description of the proposed VI mitigation approach, including phasing (tier approach) concepts and the following information:

- technical basis for the system design
- construction and implementation requirements

- any additional vapor treatment system which may be required
- component specifications and verification of ability to meet performance measures (including long-term sustainability)
- detailed testing procedures including on-the-job instructions
- permit requirements from other agencies (such as a permit to construct and a permit to operate vapor treatment systems)
- reporting requirements
- applicable engineered drawings and system diagrams

Implementation Mechanisms. Identify the LUC requirements and soil management plans.

Financial Assurance. Identify the applicable financial assurance requirements.

Additional Content. Include title and signature pages (with appropriate licensure stamp and signature; see Section 6.3.4), table of contents (with a list of tables and figures), and any other system details or proposal addressing mitigation considerations identified in Chapters 4 or 7. Additional content may be required depending upon site-specific conditions and the subsurface cleanup objectives. A draft plan submittal and agency approval will likely be necessary prior to submittal and approval of the final system engineering plans. The review and approval of the system design may require a phased approach and may include the need for pilot studies, startup testing, and agency review prior to final approval.

6.3.2 Supporting Documents

The design document for the VI mitigation system should include a discussion of other documents that may be required for its proper implementation. These documents may include, but are not limited to, the following:

Health and Safety Plan. The design document may need to include a worker health and safety plan that addresses such topics as worker training requirements, protective gear, and monitoring procedures.

Public Participation Plan. The design document should include a public participation plan that identifies future notification requirements and mechanisms. Refer to Chapter 3 and DTSC's *Vapor Intrusion Public Participation Advisory* for further discussion.

6.3.3 Response Action Implementation Report

A response action implementation report (completion report) should be submitted to DTSC upon completion of construction of the mitigation system. The completion report should include final as-built design drawings, confirmation sampling results, and provisions for determining that the response action is complete, including shut-off criteria.

6.3.4 Licensure Requirements

All VI mitigation systems should be designed, built, installed, operated, and maintained in conformance with standard geologic, engineering, and construction principles and practices using appropriately licensed professionals.

7.0 VAPOR INTRUSION MITIGATION SYSTEM IMPLEMENTATION

This chapter discusses implementation considerations of VI mitigation systems.

7.1 PROPERTY OWNER AND OCCUPANT IMPACTS, CONCERNS AND RESPONSIBILITIES

Responsible parties and stakeholders involved with VI mitigation should always keep in mind that the buildings under discussion will be occupied, or are already occupied, by people living and working within that space. For existing buildings, the owner and/or tenant preferences should be considered during the design phase. Refer to Section 6.1.1 for further discussion.

7.2 OPERATION AND MAINTENANCE

Any proposed VI mitigation should include an O&M Plan. The elements described in the following sections should be included in the O&M Plan.

7.2.1 General Performance Goals

The O&M Plan should identify specific performance goals for the VI mitigation system. Example performance goals include:

- elimination of the exposure pathway between contaminated media and indoor air receptors
- reduction of the indoor air concentrations to an acceptable level

7.2.2 Performance Measures

Performance measures should be established to ensure that the VI mitigation system is operating correctly and preventing unacceptable volatile chemical concentrations from migrating up and into the overlying structure. Performance measures should be developed on a case-by-case basis to reflect site-specific needs and conditions, and should reflect the site-specific risk management considerations discussed in Chapter 2 and indicated in Table 4. The O&M Plan should identify the performance measures for the VI mitigation system within the section that describes the goals and objectives. The plan should state the methods by which the performance goals will be tested and verified. Some examples of performance measures are provided below.

- Collecting vapor samples to demonstrate the effectiveness of the mitigation.[4] Vapor samples may be collected from within the building itself, between the foundation and the sub-slab liner system, below the sub-slab liner system within the sand/gravel blanket, or any combination thereof.
- For SSD systems, collecting pressure data to demonstrate the presence of a negative pressure field below the entire building foundation.[5] (Note: Pressure measurements are collected below a building foundation, usually below the sub-slab liner within the sand/gravel blanket of the SSD system.) A pressure differential of approximately -4 to -10 Pascal or less beneath the sub-slab liner is generally adequate to mitigate VI (USEPA, 2008a).
- For HVAC systems, measuring differential pressures and air exchange rates as well as monitoring of system operations.
- Ensuring continuous operation of the mitigation system.
- Ensuring operation in accordance with the manufacturer's specifications.

7.2.3 General Guidelines for Monitoring

The O&M Plan should identify the monitoring requirements for the VI mitigation system. These requirements should be developed on a case-by-case basis to reflect site specific needs and conditions. As indicated in Table 4, the monitoring program should consider the degree of risk or hazard being mitigated, the building use (such as residential, school, commercial/industrial), and the technology used to mitigate VI. General considerations for the monitoring program are described below and additional considerations for SSV and SSD systems are described in Sections 7.3.2 and 7.4.2, respectively. Data quality objectives should be established as part of any monitoring or sampling and analysis plan.

Consideration should be given to the potential effects of HVAC system operation on sampling activities, particularly during the hot summer months. For example, operation of an air conditioning system may create positive pressures and inhibit migration of volatile chemicals into the structure. Indoor air samples collected while the air conditioning system is operating may underestimate concentrations of volatile chemical in indoor air.

Establish Baseline Conditions. To establish a baseline for future comparison, the responsible party should conduct vapor sampling of the sub-slab or crawl space immediately after installation of the VI mitigation system for new construction, and immediately before installation, for existing construction. If a depressurization system is installed, the responsible party should also collect baseline pressure measurements. Seasonal variation should be considered when establishing the baseline conditions.

[4] The number and location of samples should be carefully selected to ensure adequate assessment of the mitigation performance goals for the entire building.
[5] The number and location of measurements should be carefully selected to ensure adequate assessment of the mitigation performance goals for the entire building.

Routine Vapor and Pressure Monitoring. Vapor samples should be collected from the sub-slab or crawl space and/or pressure measurements on a routine basis to verify the effectiveness of the mitigation system. These samples are typically collected on a semi-annual basis. Seasonal variation should be considered when establishing the sampling schedule. The considerations identified in Table 4 may assist with establishing the number and frequency of monitoring events necessary to meet the performance goals and measures.

Routine Monitoring of System Operations. The mitigation system should be monitored to ensure that it is operating effectively. For example, if building pressurization is being used to mitigate VI, routine monitoring would include assessment to determine that the HVAC system is operating so as to maintain the desired positive pressure. The O&M Plan should include equipment maintenance requirements to ensure continued operation of the system and integrity of engineering controls.

Indoor Air Quality Monitoring. As indicated in Table 4, the frequency of indoor air quality monitoring should be based on the potential risk posed by VI as well as the effectiveness of the VI mitigation system. Provisions for periodic indoor air sampling should be included in the O&M Plan to demonstrate continued effectiveness of the mitigation system. For example, high risk single family residential structures may warrant sampling every two years whereas for low risk single family residential structures it may be sufficient to sample every five years. For higher risk sites, initial indoor air sampling should be conducted seasonally. DTSC recommends two sampling events per year for the first three years or until consistent verification that the mitigation system is meeting established indoor air performance measures. The sampling frequency may be modified with technical justification and approval from DTSC.

For large or complex buildings (including schools), more frequent and/or systematic indoor air monitoring programs may be advisable depending upon level of risk and performance goals. Large or complex buildings may require a more complex network of vent piping under the building and may pose difficulty in determining pressure measurements or vapor concentrations at the interior locations farther from the outside perimeter. The network of vent piping and monitoring points should include methods to determine the effectiveness at the more interior locations. In some cases, indoor air monitoring may be more effective for determining the mitigation performance, especially in cases of existing buildings where mitigation is a retrofit to the structure.

In lieu of frequent indoor air sampling[6], volatile chemical sampling between the sub-slab liner system and the building slab could be used on a more frequent basis as a potential measure of the reduction of volatile chemical concentrations. This approach should include a CSM of potential leak mechanisms and pathways, and a discussion of how the planned monitoring above the liner would be capable of identifying such leaks.

[6] As discussed in the Vapor Intrusion Guidance, indoor air sampling is not straightforward because contaminants housed in the structure (such as paint, dry cleaning, or gun cleaner) may be contributing to volatile chemical concentrations measured in the indoor air sample.

Verification testing may require sampling from above the sub-slab liner system and within the sand/gravel blanket of the SSD system.

Soil Vapor Monitoring. In some cases, permanent vapor probes to monitor soil gas may need to be installed. Permanent vapor probes, also referred to as monitoring points or soil gas probes, can be used to evaluate the long-term behavior of soil gas adjacent to existing or future buildings. When a soil vapor monitoring program is proposed, a detailed outline of the program should be submitted to DTSC for review and approval. The outline should specify monitoring procedures, locations, frequencies, and equipment.

The design of the volatile chemical monitoring program should consider the following.

- Monitoring of subsurface vapor probes should include measurement of the concentrations of volatile chemicals, gas pressure within the probe, and the barometric pressure at the time of monitoring.
- Monitoring probes should be properly secured, capped and completed to prevent water infiltration, ambient air infiltration, accidental damage, or vandalism. Replacement or repair may be needed due to the conditions of the soil vapor probes or disturbance due to construction activities. For probe surface completions, the following components should be installed: surface seal; utility vault or box with ventilation holes and lock; and gas-tight valve or fitting for capping the sampling tube. The utility vault/box should be placed at a sufficient height to prevent water inundation or should be built to preclude water infiltration.
- Vapor probes should be periodically inspected to ensure degradation has not occurred and they are still functioning properly.

Adjacent Buildings. Buildings adjacent to properties with mitigation systems may also warrant periodic review or monitoring to verify that potential VI exceeding action levels is not occurring. The frequency of monitoring depends on the location of the building within the zone of contamination and its potential to be impacted. This monitoring may consist of soil gas monitoring, sub-slab vapor sampling, and/or indoor air sampling.

Monitoring for Combustible Gases. If the potential exists for combustible gases to be present, monitoring for these gases should be conducted at vapor monitoring points, soil gas monitoring points, along the ground surface in open areas, within crawl spaces beneath a structure, and/or in the interior of a building

7.2.4 General O&M Requirements

General activities that may be required by the O&M Plan include:

- ensuring that site conditions have not changed in a way that will impact the function or measurement of the mitigation system

- inspection of all visible components to ensure that the mitigation system is operating properly, that it has not been modified, and that components have not degraded
- surface sweeps to determine if significant changes in subsurface gas concentrations or pressure have occurred
- monitoring of changes in ownership, tenant, and/or building conditions and potential modification of the enforceable mechanism. DTSC should be notified of applicable changes within 60 days of identification of any changes.

7.2.5 Contingency Plan

The O&M Plan should reference or include a contingency plan to be implemented in the event of failure to meet the predetermined performance goals and specifications identified in the O&M Plan, or in response to monitoring data. The contingency plan should include action levels, a decision flowchart regarding specific actions and identification of the parties responsible for implementing these actions. The flowchart should also include notification requirements, response timeframes, and potential trouble-shooting actions.

7.3 IMPLEMENTATION CONSIDERATIONS FOR SUB-SLAB VENTING SYSTEMS

7.3.1 Operation and Maintenance

In addition to the general O&M activities described in Section 7.2.4, typical O&M activities for SSV systems may include:

- inspection of the area of concern, including all visible components of the venting systems and the multi-stage vapor probes
- monitoring of designated vapor probes, lowest accessible floor of the building, and enclosed areas of the building to ensure there are no potentially significant changes in subsurface gas concentrations or pressure
- for active systems, inspection of blower system to ensure all component parts are functioning
- monitoring of vent risers for flow rates and gas concentrations to confirm that the venting systems are functioning as intended
- other appropriate requirements such as routine maintenance, calibration and testing of functioning components of the venting systems in accordance with the manufacturers' schedule and recommendations, if appropriate

7.3.2 Monitoring

The monitoring program for SSV systems should address the general monitoring requirements described in Section 7.2.3. In addition, more frequent and/or systematic indoor air monitoring programs may be advisable for SSV systems depending upon level of risk and performance goals. Initially, indoor sampling should be conducted seasonally (twice a year) for the first three years or until consistent verification that the mitigation system is meeting established indoor air performance measures. Sampling frequency may be modified upon technical justification and approval from DTSC.

7.4 IMPLEMENTATION CONSIDERATIONS FOR ACTIVE SUB-SLAB DEPRESSURIZATION SYSTEMS

7.4.1 Operation and Maintenance

Typical O&M activities for SSD systems may include the items discussed in Sections 7.2.4 and 7.3.1. In addition, the blower should be checked to ensure that all components are operating properly and that the blower is drawing a sufficient vacuum.

7.4.2 Monitoring

The monitoring program for SSD systems should address the general monitoring requirements described in Section 7.2.3 as well as the following additional considerations.

Monitoring of Vent Risers. Routine monitoring of vent risers for flow rates and total volatile chemical concentrations should be conducted to confirm that the venting systems are functioning properly. Volatile chemical sampling may need to be for individual chemicals rather than total volatile chemicals to allow for comparison to site remediation soil gas monitoring. Examples where this might be advantageous include cases with unexplained changes in total volatile chemical concentrations or industrial/commercial buildings in which the occupants utilize volatile chemicals.

Indoor Air Sampling. Indoor air quality should be measured periodically, but is unlikely to be directly measured as frequently as vapor samples and pressure measurements. Indoor air quality should be acceptable as long as an adequate negative pressure is maintained below the building foundation and the mitigation system effectiveness has been demonstrated. Thus, one advantage of a SSD system over a SSV system is less frequent sampling of indoor air.

7.5 DOCUMENT SUBMITTALS

Vapor intrusion mitigation plans, reports, and other documents should be submitted to DTSC for review and approval. The level of reporting should be determined on a case-by-case basis. As applicable, documents should be signed and stamped by a registered professional who is responsible for the technical content (see Section 6.3.4).

7.5.1 Sampling and Analysis Plans

Sampling and analysis plans detailing testing, sampling methods, sample analysis, data quality objectives, QA/QC protocols, and frequency of sampling should be submitted to DTSC for review and approval prior to implementation of mitigation measures.

7.5.2 Design Document

A document detailing the VI mitigation system design should be submitted to DTSC for review and approval prior to commencement of system installation. Ideally, this document should be prepared after inspection of the building foundation and diagnostic tests. Section 6.3 provides a detailed outline for a complete mitigation system design submittal.

7.5.3 Interim Measure Construction/Final Installation Report

A report detailing the VI mitigation system installation and operation should be submitted to DTSC for review and approval after system construction. This report should include:

- as-built drawings of all system components including vacuum or sampling monitoring points
- brief account of field activities associated with system installation and startup
- initial post-startup test data and flow readings from the extraction and monitoring points
- description of back draft evaluation
- documentation that back drafting is not occurring
- complete analysis and interpretation of data
- raw data

7.5.4 Periodic Monitoring Reports

Monitoring reports on the operation and testing of the VI mitigation system should include:

- inspection reporting
- pressure test data and flow rate readings
- laboratory and screening results of indoor air and/or discharged vapor samples
- any problems and/or malfunctions (including time frame and schedule of repair)
- repairs or modifications to the system
- any complaints received

7.6 INSPECTIONS

Routine inspections of the VI mitigation system should be conducted to ensure:

- that no significant changes in site conditions have occurred
- that system components have not degraded

- adherence to the engineering controls and/or institutional controls specified in the enforceable mechanism

The inspections should address all mitigation system components, including visible components of venting systems, multi-level gas probes, and blower (if present). If an inspection determines that the building foundation or components of the mitigation system have been modified by the owner or tenant, appropriate testing should be conducted to ensure that performance measures are being met.

The frequency of inspections should be based on site-specific considerations. Annual inspections may be appropriate for some sites whereas other sites may warrant more frequent inspections. Higher inspection frequencies may be appropriate for the first year of system operation followed by a reduced frequency after one year of efficient operation. Inspection reports should be submitted to DTSC for review pursuant to the enforceable mechanism and/or LUC requirements.

7.7 FIVE-YEAR REVIEWS

CERCLA and state law require five-year reviews for a response action that results in hazardous substances remaining at the site at concentrations that would preclude unrestricted land use. The O&M Plan, as well as any regulatory oversight agreement, enforceable mechanism, or LUC, should include provisions for conducting five-year reviews. The purpose of the five-year review is to ensure that the response action remains protective of human health and the environment, is functioning as designed, and is maintained appropriately. The review generally addresses the following questions:

- Are the response action and mitigation system functioning as intended?
- Are the cleanup and/or mitigation objectives, goals, and criteria used at the time of response action determination still valid?
- Have there been significant changes in the distribution or concentrations of volatile chemicals at the site?
- Are modifications needed to make the O&M Plan more effective?

The scope of the five-year review may be outlined in the O&M Plan or in a separate workplan developed for a specific review. The review of the response action and/or mitigation would typically consist of:

- notifying the community that the review is being conducted
- site inspection and review of the response action and mitigation to answer the above questions
- preparing a report that details the findings of the review for regulatory agency approval

The *Comprehensive Five-Year Review Guidance* (USEPA, 2001) may be a useful resource when conducting these reviews.

Depending on site-specific considerations, DTSC and/or the responsible party may conduct the site inspection and/or technical assessment. If the responsible party conducts the inspection or assessment, DTSC staff will review the report and make recommendations to ensure that the response action and mitigation remain effective, to identify milestones toward achieving or improving effectiveness. and to provide a schedule to accomplish necessary tasks.

7.8 ENFORCEABLE MECHANISMS

To address DTSC oversight and cost recovery, mitigation system O&M must occur through a DTSC legal counsel approved enforceable mechanism, such as a corrective action consent agreement, LUC, consent order, O&M agreement, post-closure permit, or other legally binding agreement. Any enforceable mechanism should include the following:

- O&M Plan
- financial assurance requirements (if not part of the O&M Plan)
- closure specifications
- contingency plan (if not part of the O&M Plan)
- applicable contacts
- allowance for DTSC access as necessary
- provisions for enforcement
- DTSC cost estimation with provision for annual updates
- project schedule

7.9 FINANCIAL ASSURANCE

O&M costs should be the responsibility of the responsible party/site owner and identified as such in the enforceable mechanism (Section 7.8). The responsible party/site owner should establish and maintain a sufficient and enforceable financial assurance mechanism for costs associated with implementation of the VI mitigation response action, O&M activities, LUC compliance, five-year reviews, DTSC's oversight, and any other applicable costs associated with the implementation and use of a VI mitigation system.

7.10 ACCESS AGREEMENTS

To address the concerns of affected parties, an access agreement should be executed prior to entering the property for testing and/or construction. Example situations to be addressed in access agreements include:

- property owners and tenants granting access for testing and/or construction
- future liability for landlords

- employees concerned that VI is occurring at their place of business
- disrupting business operations of tenants
- privacy issues for homeowners

Access for O&M purposes should be authorized by the applicable LUC. Typically, such a covenant would require access for DTSC oversight and other activities necessary to protect the public health and safety or the environment. The LUC would also address access for the person or entity responsible for implementing O&M. These access rights are binding on future owners and occupiers of the property. The owner who signs the covenant and all future owners are required to incorporate the covenant by reference into each and every deed, lease, rental agreement, and any other document that creates a right to use or occupy any portion of the property subject to the covenant.

7.11 LAND USE COVENANTS AND INSTITUTIONAL CONTROLS

When VI mitigation at a structure is necessary, whether as an interim response action or in conjunction with a final response action, the mitigation requirement should be included in a LUC (Covenant to Restrict Use of Property, Environmental Restriction). The LUC may include other ICs with prescribed notifications, prohibitions, restrictions and requirements that must be utilized to ensure O&M and disclosure of the risks, restrictions, and requirements to future buyers and occupants.

The following provisions should be included in the LUC:

- notice of the existing conditions known to the environmental agency that may cause potential unacceptable risk from VI
- prohibition against specific uses of the property
- prohibition against interference with the VI mitigation system
- prohibition against activities that will disturb impacted soil without DTSC approval
- right of access to the property for DTSC to inspect, monitor, and perform other activities relative to the VI mitigation system
- right of access to the property for the person responsible for implementing the O&M activities relative to the VI mitigation system
- inspection and reporting requirements for the owner of the property

If existing conditions without mitigation may cause unacceptable future risk to receptors, effective legal notification will be required to be provided to future buyers of the property, and occupants of future developments, or re-developments on the property.

LUCs must be compliant with California Code of Regulations, title 22, Division 4.5, Chapter 39, Section 67391.1, approved by DTSC legal counsel, and publicly recorded in the county recorder's office. DTSC has an approved model Covenant to Restrict Use of Property, Environmental Restriction that should be utilized when developing a site-specific LUC.

7.12 EMISSIONS AND DISCHARGES

The need for air permits should be determined for all sites in order to comply with applicable state or local air quality control regulations. In certain cases, particularly those that involve large numbers of structures requiring mitigation within a certain area or those where the mitigation creates high vapor flux rates, it is possible that redirection of soil gases from beneath the building to the ambient air may result in unacceptably high cumulative air quality impacts at receptor points within the community. In such cases, it may be necessary to apply emission controls on mitigation systems to reduce the concentrations of volatile chemicals being discharged to the atmosphere. Generally, where unacceptable ambient air impacts exist, a dispersion modeling analysis of the emissions point(s) may be used to estimate whether resulting ambient air quality impacts exceed applicable state toxic thresholds or other health-based standards. Finally, in some instances, a community ambient air monitoring network may be established to demonstrate that the local population is not being exposed to unacceptable levels of air contaminants resulting from the VI mitigation processes.

7.13 COORDINATION WITH OTHER AGENCIES

The responsible party should coordinate with state and local agencies that have jurisdiction for sites requiring VI mitigation. Examples of local agencies that may require coordination efforts are discussed below. Local agency involvement should start early in the mitigation process to alleviate potential construction delays. Where overlapping regulatory authority or requirements are identified, DTSC should come to an agreement with the other applicable agencies to ensure that the project strategies are compatible and requirements can be met. In cases where oversight authority may be overlapping or redundant, an agreement (such as a Memorandum of Understanding) should be made between the applicable entities for designation of a single oversight agency.

Air Discharge Permits. Permits or authorizations from the local air pollution control district (APCD) or air quality management district (AQMD) may be required for venting systems that exhaust to atmosphere. DTSC recommends that the local APCD or AQMD be consulted to confirm their requirements, prior to the submittal of initial designs to DTSC.

Building Codes. The mitigation design criteria need to be compatible with applicable local and state building, electrical, and energy codes. Some building HVAC requirements may impact the mitigation design considerations and, thus, must be considered at the time of building design. The responsible party should coordinate with the applicable local planning and building departments for mitigation system design review concurrent with DTSC's engineering review and approval.

Land Use. Local county and city land use decisions and requirements may impact or influence future use of the project site. Discussions and coordination with local land use authorities, including redevelopment agencies, should begin as soon as possible once it is determined that vapor phase contaminants are a concern and/or there is a potential for VI.

Fire Departments. The mitigation design criteria need to be compatible with applicable local and state building fire codes. The responsible party should coordinate with the applicable local fire agency on mitigation system design review concurrent with DTSC's engineering review and approval. Coordination with the local fire agency is especially important when methane is present as a volatile chemical of concern to ensure both compatibility and consistency with local agency requirements for methane.

7.14 CALIFORNIA ENVIRONMENTAL QUALITY ACT

CEQA requires DTSC to analyze potential environmental impacts for discretionary project decisions, such as DTSC's approval of interim response actions or the proposed final response action. The approval of a VI mitigation system is a discretionary project decision for which a CEQA evaluation would be required. Cumulative impacts of all media, including single and/or multiple points of discharge from system vents, are considered as part of the CEQA evaluation. Project proponents are required to submit all necessary environmental information for DTSC to complete a CEQA evaluation. The DTSC project manager, in conjunction with DTSC CEQA support staff, completes and processes necessary CEQA documents.

As interim responses, most VI mitigation projects are not likely to require a full Environmental Impact Report (EIR) level of analysis or procedure. Generally, it would be expected that a VI mitigation project would qualify under a notice of exemption, negative declaration, or a mitigated negative declaration. Some large scale projects, such as new residential developments, could warrant an EIR.

Generally, a new development proposal (commercial, industrial, or residential) will require an EIR for which the local land use agency would be considered the lead agency. In such cases the VI mitigation proposal can be included as part of the analysis and a separate CEQA evaluation would not be required. In such cases, DTSC would be a responsible agency and would coordinate with and provide input to the lead agency. It is best not to separate the development analysis from the VI mitigation to ensure compatibility and consistency with identified CEQA related mitigation measures.

7.15 COMMINGLED CONTAMINANTS/PLUMES

It is not uncommon to have situations where there are commingled contaminants or plumes. Care should be taken to address all aspects of the commingled contaminants relative to mitigation needs, while coordinating with other agencies as discussed in Section 7.13.

Methane and/or radon are common contaminants which may be commingled with VOC contamination. To ensure compatibly and consistency of mitigation strategies applied to school buildings, DTSC's *Advisory on Methane Assessment and Common Remedies at School Sites* (DTSC, 2005) should be consulted. In addition, local jurisdictions often have guidance specific to methane and/or radon which should be consulted when developing a mitigation strategy.

7.16 MULTIPLE RESPONSIBLE PARTIES

In cases where multiple responsible parties share in the obligations for the response action, mitigation, and long-term care of a site, the enforceable mechanism (see Section 7.8) should include all designated responsible parties and clearly identify each responsible party's obligations and responsibilities. Coordination with all responsible parties should begin early and continue throughout the process of mitigating the VI risk. This coordination will ensure that applicable considerations are addressed.

7.17 TERMINATION OF BUILDING CONTROLS

Subsurface remediation efforts will eventually reduce volatile chemical concentrations in soil, soil gas, and/or groundwater to levels that no longer require remediation. At this point, VI mitigation systems could be shutdown and/or removed, depending on the preferences of the building owners and obligations of responsible parties. Upon shutdown or removal, O&M requirements would cease.

Early in the decision-making process, stakeholders should consider how to determine when VI mitigation is no longer required. This decision will affect the type of data that will need to be collected during the operating period of the mitigation system (see Section 7.2.3) and should be part of the data quality objective process.

The response action implementation report should include specific provisions for determining that the response action is complete, including the termination of the VI mitigation system(s). A confirmation sampling and analysis plan should be a part of these provisions. The responsible party should conduct subsequent sampling rounds to ensure the absence of contaminant rebounds and to verify the appropriateness of system termination.

The response action completion report should contain the confirmation sampling results and justification for termination of the VI mitigation system. Vapor mitigation should only be terminated when soil, soil gas, and/or groundwater concentrations have achieved and maintained heath-based remediation goals. Responsible parties should not use indoor air sample results alone to justify mitigation termination. Provisions for termination of mitigation systems should include: 1) specific procedures for the notification of owners/tenants, 2) removal of associated LUCs or other ICs, 3) notification of other applicable stakeholders, and 4) instructions regarding the removal of physical system components, if desired by the owner/tenant.

8.0 REFERENCES AND ADDITIONAL RESOURCES

8.1 REFERENCES

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GLOSSARY

Ambient air. Refers to outdoor air at a VI site and reflects background air concentrations of volatile chemicals from numerous anthropogenic sources, such as vehicle exhaust, industrial stack emissions, etc.

Background air. See Ambient Air.

Brownfields. Brownfields are properties that are contaminated, or thought to be contaminated, and are underutilized due to perceived remediation costs and liability concerns.

Buildings. Buildings include any structure in which current or future occupants could potentially contact contaminated indoor air.

CERCLA. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was enacted by Congress on December 11, 1980, and amended in 1986, by the Superfund Amendments and Reauthorization Act (SARA). This law provided broad federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health or the environment. CERCLA established prohibitions and requirements concerning closed and abandoned hazardous waste sites, provided for liability of persons responsible for releases of hazardous waste at these sites; and established a trust fund to provide for cleanup when no responsible party could be identified.

CEQA. The California Environmental Quality Act (Public Resources Code, §21000 et seq) requires public agencies to consider and disclose the environmental implications of their decisions, and to eliminate or reduce the significant environmental impacts of their decisions whenever it is feasible to do so.

CHHSLs. Developed by the Office of Environmental Health Hazard Assessment (OEHHA) as a tool to assist in the evaluation of contaminated sites and to estimate the degree of effort that may be necessary to remediate a contaminated property. CHHSLs are concentrations of contaminants in soil gas or indoor air that the Cal/EPA considers to be below thresholds of concern for risks to human health.

Cleanup goal. Contaminant concentration against which the success or completeness of a cleanup effort is evaluated.

Corrective Measures Study. The CMS is the mechanism for the development, screening, and detailed evaluation of alternative corrective actions under the RCRA corrective action process.

Degradation product. Refers to the natural degradation of volatile chemicals in soil, soil gas, or groundwater due to microbial degradation or an abiotic process. As an example, TCE will biodegrade under anaerobic conditions to cis-1,2-DCE and vinyl chloride.

Exposure pathway. The way a chemical comes into contact with a receptor. For VI, volatile chemicals in groundwater will migrate into the air-filled spaces in soil (soil gas); volatile chemicals in soil gas will migrate through the soil column and through cracks in the building foundation into the indoor air where they can ultimately be inhaled by the building occupants.

Feasibility Study. Under the National Contingency Plan process (used by DTSC under California HSC chapter 6.8), the feasibility study is the mechanism for the development, screening, and detailed evaluation of alternative remedial actions.

Hazard Index. Refers to the cumulative, noncarcinogenic health hazard estimate for a site. The cumulative hazard index is the sum of the hazard quotients for individual chemicals and is defined as:

$$\text{Hazard Index} = \sum_{i=1}^{n} \frac{\textit{inhalation dose of chemical } i}{\textit{reference dose of chemical } i}$$

HSAA. Hazardous Substances Account Act, Health and Safety Code, division 20, chapter 6.8.

HWCL. Hazardous Waste Control Law, Health and Safety Code, division 20, chapter 6.5.

Institutional Control. Institutional controls are actions, such as legal controls, that help minimize the potential for human exposure to contamination by ensuring appropriate land or resource use.

Interim actions. Interim actions are short-term response actions performed pursuant to CERCLA or HSAA to control on-going risks while site characterization is underway or before a final response action is selected.

Interim measures. Interim measures are short-term response actions performed pursuant to RCRA or HWCA to control on-going risks while site characterization is underway or before a final response action is selected.

Land Use Covenant. Written instruments used to require compliance with certain obligations and restrict use of property. Land use covenants are recorded at the county recorder's office so that they will be found during a title search of the property deed.

Mitigation. Engineering controls taken to reduce the entry of vapors into the building until cleanup goals in the subsurface are met.

Non-time-critical removal action. Non-time-critical removal actions, as defined by CERCLA, are removal actions that the lead agency determines, based on the site evaluation are appropriate, and a planning period of at least six months is available before on-site activities must begin.

RCRA. The Resource Conservation and Recovery Act, an amendment to the Solid Waste Disposal Act to address the huge volumes of municipal and industrial solid waste generated nationwide. Under RCRA, USEPA has the authority to control hazardous waste from the "cradle-to-grave." This includes the generation, transportation, treatment, storage, and disposal of hazardous waste. RCRA also sets forth a framework for the management of non-hazardous wastes. [Title 40 of the Code of Federal Regulations, Parts 239 through 282]

Receptor. Refers to the hypothetical (future buildings) or actual person being exposed to volatile chemicals from VI. The amount of exposure will be defined by the land use such as residential, commercial/industrial, school, etc. and how much time a person spends on-site.

Remedial Action Plan. Under the HSAA, the Remedial Action Plan is the response action selection document for a remedial action for which the capital costs of implementation are projected to cost $2 million or more.

Remediation. An action that reduces the level of contamination in environmental media (such as soil, soil gas, and/or groundwater) that are acting as the source of the indoor air vapors.

Removal Action Workplan. Under the HSAA, the Removal Action Workplan is the response action selection document for a nonemergency removal action that is projected to cost less than $2 million at a hazardous substance release site. Typically, these are short-term actions designed to stabilize or cleanup a site posing a threat to human health or the environment, either as an interim action or the final remedy.

Response action. Facility closure, corrective action, remedial action, or other response action to be undertaken pursuant to division 20 of the Health and Safety Code.

Risk assessment. The scientific process used to estimate the likelihood that a chemical detected at a site may be harmful to people and the environment.

Risk management. The process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of scientific, legal, economic, political, and social factors.

Source remediation. See Remediation.

APPENDIX A
EXAMPLE DESIGN BASIS/CRITERIA FOR SUB-SLAB DEPRESSURIZATION SYSTEMS

This section identifies example design considerations for SSD systems installed in existing buildings and installed in conjunction with new construction.

A.1 Existing Building Design Requirements (No Sub-Slab Liner)

This section provides more specific design considerations for installation of a SSD system in an existing building with a slab foundation. These retrofit systems will lack sub-slab liners because of the difficulty of installing liners under slabs on existing buildings. This section could also be applied to existing buildings with crawl space foundations. The following recommendations should be considered in the design of a SSD system in an existing building.

Collection Pipe Spacing and Diameter. Soil properties (such as soil gas permeability and diffusion coefficients) should be considered in the design and spacing of the sub-slab collection piping system. When using horizontal pipes, the pipes should be placed such that all points immediately beneath the slab are located within 20 to 25 feet of a manifold pipe. The subsurface gas collection pipes should be perforated and at least two inches in diameter. A low profile collection and venting system may be used as an alternative to round collection pipes. In smaller, single family residences, a single suction point may suffice.

Collection Pipe Layout. Collection piping for existing buildings may be either vertically or horizontally installed. Pipe orientation should be dictated by site-specific conditions. Typically, small buildings (such as single family homes) can be mitigated with vertical collection points where the groundwater table is sufficiently deep, in similar fashion to radon mitigation. For larger buildings, horizontal piping may be warranted. Such piping could be installed through the foundation by trenching or installed beneath the building via horizontal drilling. The horizontal collection piping should extend the full width of the building and be located no more than five feet beneath the slab. The collection/vent piping system should be thread connected, not solvent-welded, unless it can be shown that the solvent does not contain any volatile chemicals of concern. The need for drainage or de-watering improvements to prevent flooding of any portion of the collection/vent piping should be evaluated and suitable improvements should be installed to insure the proper operation of the collection pipe system.

Vent Riser Design. The underground gas collection pipes should be connected to solid vent risers that extend above the building. The vent risers should be equipped with a sampling port and fitted with a non-restricting rain guard to prevent precipitation and debris from entering the piping system. Installation of a turbine as a vent cap may also be applicable. Vent risers should be properly secured (such as enclosed within wall cavities or pipe chases) to prevent damage. A minimum of two vertical vent risers [equivalent two 2-inch diameter] for the first 10,000 square feet of building footprint area and one additional vertical vent riser for each additional 10,000 square feet of building footprint should be provided. Whenever practicable, vent riser pipes should terminate above the highest roof of the building and above the highest ridge. Vent riser pipes attached to, or penetrating the sides of, buildings should be located at least 10 feet above ground level, at least one foot above the edge of the roof, and at least 10 feet away from any window, door, or other opening (ASTM 2007b). However, the riser pipe position should be selected on a case-by-case basis and should consider the building roof design.

Vent Riser Diameter. At a minimum, each vent riser piping should consist of 2-inch diameter pipes. Where necessary for structural reasons, the size of the vent risers may be reduced to 1.5-inch diameter provided additional vent risers are installed to provide a flow capacity equivalent to the appropriate number of 2-inch diameter vent risers.

Utility Trench. Utility trenches are generally used in large buildings (such as offices, schools, and commercial/industrial) for utility runs and may become conduits for soil vapors to enter the building. Utility trench dams should be installed as a precautionary measure to reduce the potential for soil vapor to migrate beneath a structure through the relatively permeable trench backfill. An impermeable dam or plug constructed of bentonite-soil mixture, or sand-cement slurry (or equivalent) should be installed in all utility trenches that are backfilled with sand or other permeable material for new or replacement utility lines (such as water, sewer, phone, electrical, and cable). These dams should extend for a distance of at least three feet from the perimeter of the structure and from at least six inches above the bottom of the perimeter footing to the base of the trench.

Conduit Seals. Conduit seals should be provided at the termination of all utility conduits to reduce the potential for combustible gas migration along the conduit to the interior of the building. These seals should be constructed of closed cell polyurethane foam, or other inert gas-impermeable material, extending a minimum of six conduit diameters or six inches, whichever is greater, into the conduit. Wye seals should not be used for main electrical feed lines.

Electrical conduits should be provided with seals as required by the appropriate sections of the National Electrical Code (NFPA 70) as presented in Article 500 Hazardous (Classified) Locations Class I, II, and III, Divisions 1 and 2. All NFPA 70 requirements should be met for all work in any classified area, given the specified classifications of the project.

The local APCD or AQMD may require permits or authorizations for a passive volatile chemicals collection and venting system that exhausts to atmosphere. The local APCD or AQMD should be contacted to confirm their requirements.

Volatile Chemical Monitoring Program. All recommendations for a volatile chemical monitoring program (see Chapter 7) are generally applicable.

A.2 New Construction Design Requirements for Sub-Slab Depressurization Systems

This section recommends design requirements for installation of a SSD system and sub-slab liner system concurrent with new construction of buildings or structures. All considerations for the existing structure retrofit mitigation system (see Section A.1) are also generally applicable in a new structure, except as described below.

Pipe Spacing Design. If an appropriate permeable subgrade material is provided for the collection piping (e.g., sand or gravel), evaluation of native soil permeability characteristics may not be necessary for the pipe spacing design.

Sub-slab Liner System. A sub-slab liner system should meet the following requirements:

- Sub-slab liners should be installed by qualified personnel, preferably with manufacturer certification.
- Sub-slab liners should be constructed with approved materials and thicknesses (e.g., 60-mil or 0.060 inch of high-density polyethylene, rubberized asphalt, or equivalent).
- Sub-slab liners should be placed a maximum of one foot below the floor slab and a maximum of six inches above the gas collection piping.
- Sub-slab liners should be anchored to footings.
- Protective layers consisting of sand (at a minimum, two inches or thicker) and/or geotextile (at a minimum, six ounces per square yard) should be laid below and above the sub-slab liner.
- Because of seismic concerns, the sub-slab liner should not pass below footings and/or stiffener beams of the structure without a careful evaluation and confirmation data to support the beneath footing passage.
- Gas tight seals (e.g., boots) should be provided at all pipe or conduit penetrations through the sub-slab liner. Gas tight seals should be provided where the sub-slab liner attaches to interior and perimeter footings.

A.3 New Construction Design Requirements for Active Sub-Slab Venting Systems

Some volatile chemicals may not be adequately vented via passive venting, because of high concentrations, being heavier than air, or other site-specific conditions. In these instances, active venting may be necessary. All considerations for the existing structure retrofit and new construction mitigation systems described in Sections A.1 and A.2 are also generally applicable for an active SSV system with sub-slab liner in a new structure. However, an active SSV system would also include a properly sized blower. An air permit from the local APCD or AQMD may be required for an active SSV system. The APCD or AQMD should be contacted regarding the permit requirements.

APPENDIX B
EXAMPLE OF DESIGN AND INSTALLATION REQUIREMENTS FOR SUB-SLAB DEPRESSURIZATION SYSTEMS

Note: The requirements listed below are extracted from the Orange County Fire Authority Guidance for Combustible Soil Gas Hazard Mitigation (2008), as modified by DTSC. These are reprinted as a design example and are not requirements from DTSC.

SSD systems should be designed and installed in conformance with standard engineering and construction principles and practices (see Section 6.3.4). Installation should be in accordance with applicable Uniform Building, Mechanical, and Plumbing Codes.

1) Ventilation trenches should be placed such that no portion of the foundation is more than 25 feet from a ventilation trench. Trench cross section dimensions should not be less than 12 inches by 12 inches. Ventilation trenches should be back filled with pea gravel approximately 3/8 inch in diameter, or other material of similar size and porosity. A preferred alternative to vent trenches is a continuous gravel blanket with a collection piping arrangement in the same configuration used with the trench design.

2) Ventilation trenches should be provided with perforated pipe of not less than four inches in diameter. The total pipe perforation area should be at least equal to five percent of the total surface area of the pipe. Perforated pipe should be located a minimum of four inches below the foundation.

3) Where piping transitions through building footings, the penetration should be accomplished in compliance with the Uniform Building Code and with the approval of the Building official.

4) Perforated pipe should be connected to vertical ventilation pipe. Vertical ventilation pipe should be not less than 3 inches in diameter and should be constructed of materials specified by the Uniform Plumbing and Mechanical Codes. All joints should be tightly sealed with approved materials. Ventilation pipe may be located within walls/chases or should be similarly protected from physical damage. Ventilation pipes should terminate at a height determined acceptable by the design engineer, but not less than 18 inches above the adjacent level. Ventilation pipes should be located at least three feet from a parapet wall. Ventilation pipes should terminate at a distance of at least ten feet from any building opening or air intake and at least four feet from any property line. Any ventilation pipe located within an open yard should terminate at a height of not less than ten feet above adjacent grade.

5) The vertical collection pipe should be equipped with a sampling port. The discharge point of a ventilation pipe should be provided with a non-restricting screened rain guard to prevent precipitation and debris from entering the piping system. The electrical classification of the area surrounding the discharge point should be taken into account in the overall building design. Termination of all ventilation pipes should

be provided with a “T” connection or other approved rain cap to prevent the intrusion of rainwater.

6) Ventilation pipes should be clearly marked to indicate that the pipe may contain volatile chemicals. This may be accomplished through stencils, labels, or other methods. Pipes should be marked near their termination point and at five-foot intervals along the remainder of the ventilation pipe. This includes sections encased within walls or other enclosures. An example of an acceptable identifier would be the words “Potentially Hazardous Volatile Compounds” printed in two-inch letters.

7) All underground electrical conduits penetrating the slab or foundation of the building should be provided with a seal-off device as normally found on classified electrical installations. For purposes of design, sub-slab areas should be considered a Class 1 Division 2 hazardous area classification (NFPA 70 Article 500).

APPENDIX C
DIAGNOSTIC TESTING OF AIR FLOW CHARACTERISTICS BENEATH EXISTING BUILDINGS

Note: The content of this appendix is modified from the Massachusetts Department of Environmental Protection guidance entitled *Guidelines for the Design, Installation, and Operation of Sub-Slab Depressurization Systems* (1995).

The air flow characteristics and capacity of the material(s) beneath the slab should be quantitatively determined by diagnostic testing, a procedure analogous to conducting a soil vapor extraction pilot test. This is an important step in the SSD design process, and should always be performed prior to the design and installation of a SSD system. The objective of diagnostic testing is to investigate and evaluate the development of a negative pressure field, via the induced air flow beneath the existing building slab. This information is used to determine whether a low pressure/high flow or high pressure/low flow system is necessary, and to determine the number and location of necessary system extraction points.

The scope (or complexity) of the diagnostic testing is a function of the building size and the presence of structures that may interfere with air flow. For larger buildings, such as commercial buildings and school buildings, more extensive and involved sub-slab diagnostics are essential. Structures such as utility tunnel floors and walls, crawl spaces, internal continuous footings, and/or frost walls should be considered in the diagnostic evaluations, as they can impede air flow.

Diagnostic testing is conducted by drilling small diameter holes through a building slab, applying a vacuum to one hole (an extraction hole), and measuring pressure drops at surrounding test holes (observation holes). Extraction and observation holes should be placed in the most unobtrusive locations possible; utility rooms and closets are good choices. Care must be taken to avoid damaging sub-slab utilities or conduits. Generally, the extraction hole should be at least 3/4 inches in diameter and the test holes should be 3/8 to 5/8 inches in diameter. Test holes should be placed at representative locations, such that the size of the effective pressure field under the slab may be evaluated.

Typically, a "shop vacuum" unit is used to evacuate sub-slab air from the extraction hole. During the test, the extraction vacuum and flow rate should not exceed the capacity of potential SSD system fans. The pressure drop and flow rate at this extraction point should be monitored and recorded. Pressure drops at the test holes should be measured quantitatively with a pressure gauge (e.g., a magnehelic gauge).

The vacuum and flow rate of the “shop vacuum” used for testing should be recorded to provide an assessment of the testing parameters in conjunction with the test results. Literature regarding specifications for typical shop vacuums indicates a potential noise level of approximately 75 to 85 decibels. Therefore, the potential noise levels during testing procedures should be considered relative to impacts on building occupants and the need for worker hearing protection. An additional precaution during testing procedures is the consideration of the shop vacuum exhaust emissions. For health and safety considerations, the shop vacuum exhaust should be directed to and vented outside of the building.

Atmospheric pressure may be of importance at sites where diagnostic testing indicates marginal negative pressure readings. In such cases, barometric pressure data should be obtained and reviewed for the day of testing, and previous several days. A trend of rising barometric pressure tends to promote advection of air into the ground, which may be falsely interpreted as a negative pressure field created during diagnostic tests. Where this concern exists, the testing should be repeated during a time of falling barometric pressures.

Two approaches may be used to monitor and document the development of a negative pressure field: pressure testing and smoke testing. Pressure testing provides a direct and quantitative means to measure a negative pressure field. However, in cases where very permeable fills/subsoils are present, large volumes of air can be moved with relatively little pressure drop, undetectable by even the most sensitive gauge. In these cases, the creation of a negative pressure field can be verified by smoke tests, which demonstrate the advection of smoke (air) into the ground (i.e., through the slab).

Following the test, the diagnostic extraction and test holes (and any leaked areas) should be sealed with a Portland cement grout, although at least one or two holes should be temporarily sealed with a removable sealant, such as caulk, until after installation of the final SSD system, in order to provide points to demonstrate establishment of a negative pressure field.

The diagnostic testing should also address the potential for back drafting both during the testing procedures and in consideration of the mitigation design. See Section 6.1.3 for additional discussion of back drafting considerations.