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OSWER FINAL GUIDANCE FOR ASSESSING AND MITIGATING THE VAPOR INTRUSION PATHWAY FROM SUBSURFACE SOURCES TO INDOOR AIR
(EXTERNAL REVIEW DRAFT)

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U.S. Environmental Protection Agency

Office of Solid Waste and Emergency Response

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DISCLAIMER

This document presents current technical and policy recommendations of the U.S. Environmental Protection Agency (EPA) based on our current understanding of vapor intrusion into indoor air from subsurface sources. This guidance document does not impose any requirements or obligations on the U.S. Environmental Protection Agency (EPA), the states, or the regulated community. Rather, the sources of authority and requirements for addressing subsurface vapor intrusion are the relevant statutes and regulations. Decisions regarding a particular situation should be made based upon statutory and regulatory authority. EPA decision-makers retain the discretion to adopt or approve approaches on a case-by-case basis that differ from this guidance document, where appropriate, as long as the administrative record supporting its decision provides an adequate basis and reasoned explanation for doing so.

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ACRONYMS AND ABBREVIATIONS

ACH	air changes per hour (air exchanges per hour)
ADT	active depressurization technology
ANSI	American National Standards Institute
ASQ	American Society for Quality
ASTM	American Society for Testing and Materials
ASTSWMO	Association of State and Territorial Solid Waste Management Officials
ATSDR	Agency for Toxic Substances and Disease Registry
BTEX	benzene, toluene, ethylbenzene, xylenes
BWD	block-wall depressurization
CalEPA	California Environmental Protection Agency
CASRN	Chemical Abstracts Service Registry Number
CEI	Community Engagement Initiative
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CHC	chlorinated hydrocarbon
CIC	Community Involvement Coordinator
CIO	Chief Information Officer
CIP	community involvement plan
CMS	corrective measures study
CSM	conceptual site model
DNAPL	dense non-aqueous-phase liquid
DoD	U.S. Department of Defense
DoN	U.S. Department of Navy
DQO	data quality objective
DTD	drain-tile depressurization
EI	environmental indicator
EPA	U.S. Environmental Protection Agency
FN	false negative
FP	false positive
FR	Federal Register
FS	feasibility study

FYR	five-year review
HI	Hazard Index
HQ	Hazard Quotient
HVAC	heating, ventilation and air conditioning
IC	institutional control
ICIAP	Institutional Controls Implementation and Assurance Plan
IDLH	immediately dangerous to life or health
ITRC	Interstate Technology and Regulatory Council
LCR	lifetime cancer risk
LEL	lower explosive limit
LEP	limited English proficiency
LNAPL	light non-aqueous-phase liquid
LTS	long-term stewardship
MADEP	Massachusetts Department of Environmental Protection
NAPL	non-aqueous-phase liquid
NAS	National Academy of Sciences
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NFA	No Further Action
NIST	National Institute of Standards and Technology
NPL	National Priorities List
NRC	National Research Council
NYSDOH	New York State Department of Health
O&M	operation and maintenance
OIG	Office of the Inspector General
OSC	on-scene coordinator
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OUST	Office of Underground Storage Tanks
PCE	tetrachloroethene
PEM	preemptive mitigation
PID	photoionization detector
P.E.	Professional Engineer
ppbv	parts per billion by volume

PRP	potentially responsible party
QAPP	quality assurance project plan
QMP	quality management plan
RCRA	Resource Conservation and Recovery Act
RfC	inhalation reference concentration
RFI	RCRA facility investigation
RI	remedial investigation
RML	regional removal management level
ROD	Record of Decision
RPM	remedial project manager
SMD	sub-membrane depressurization
SSD	sub-slab depressurization
TAGA	trace atmospheric gas analyzer
TCE	trichloroethylene
UFP-QAPP	Uniform Federal Policy for Quality Assurance Project Plans
UECA	Uniform Environmental Covenants Act
USPS	U.S. Postal Service
UST	underground storage tank
UU/UE	unlimited use/unlimited exposure
VI	vapor intrusion
VISL	vapor intrusion screening level
VOC	volatile organic compound
VC	vinyl chloride

1.0 INTRODUCTION

This guidance document was prepared by the U.S. Environmental Protection Agency (EPA) through the cooperative efforts of a team of EPA Headquarters and Regional staff, known as the Vapor Intrusion Intra-Agency Workgroup (Workgroup). Drafts of this document were subjected to a comprehensive, consultative peer-input process, which included comments and other contributions from Workgroup members representing several EPA offices and the EPA's Vapor Intrusion Forum.[1] Public comments submitted from 2002 through 2012 and recommendations of the Office of Inspector General (OIG) were considered in developing this guidance document.

This document comprises EPA's final vapor intrusion guidance and is referred to herein as the "Final VI Guidance." It describes a recommended framework for assessing vapor intrusion that relies upon collecting and evaluating multiple lines of evidence to support risk management decisions. It also provides guidance about monitoring and terminating building mitigation systems. Peer-reviewed literature, peer-reviewed technical reports, and other pertinent information that support development or implementation of the Final VI Guidance are cited within.

This introductory section: defines the term "vapor intrusion"; summarizes EPA's statutory authorities to protect human populations from vapor intrusion; summarizes the intended uses of the Final VI Guidance, including the applicability of the guidance to petroleum hydrocarbons and other potentially biodegradable chemicals and to nonresidential buildings; identifies supplemental guidance documents and key technical resources that facilitate consideration of the recommendations in the guidance; provides a concise historical accounting of the development of the guidance; describes how the public was involved in the development of the Final VI Guidance; and provides an overview of the organization of the guidance.

1.1 Definition of Vapor Intrusion

Certain hazardous chemicals that are released into the subsurface as liquids or solids may form hazardous gases (i.e., vapors) that migrate through the vadose zone and eventually enter buildings as a gas[2] by migrating through cracks and gaps in basement floors and walls or foundations, including perforations due to utility conduits and any other openings (e.g., sump pits). Vapor intrusion is the general term given to migration of hazardous vapors from any subsurface contaminant source, such as contaminated soil or groundwater, through the vadose zone and into indoor air. Vapor intrusion can occur in a broad range of land use settings, including residential, commercial, and industrial, and affect buildings with virtually any foundation type (e.g., basement, crawl space(s), or slab on grade). Vapor intrusion is similar to radon intrusion in that mechanisms of subsurface vapor migration and soil gas entry into

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[1] The EPA Vapor Intrusion Forum is an intra-Agency group engaged in sharing information, technical resources, and perspectives pertaining to vapor intrusion assessment and mitigation.

[2] The terms 'gas' and 'vapor' are used inter-changeably in this document. Both refer to a substance in the gaseous state, as distinguished from the liquid or solid state.

buildings are similar for radon and volatile, hazardous chemicals of concern to EPA's programs.[3]

Vapor intrusion is widely recognized as a potentially significant cause of human exposure to "volatile" (i.e., vapor-forming) hazardous chemicals in indoor spaces. When vapor intrusion is significant, concentrations of toxic vapors can accumulate indoors to a point where the health of the occupants (e.g., residents, workers, etc.) in those buildings could be at risk.[4] In addition, methane and certain other volatile chemicals can pose explosion hazards when they accumulate in confined spaces, in addition to the toxicity threats they may pose in occupied spaces.

Section 2.0 describes the vapor intrusion pathway in greater detail.

1.2 Statutory Authorities

Protection of human health is a critical mandate underlying several federal statutes, including the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended,[5] and the Resource Conservation and Recovery Act (RCRA), as amended.[6] Protection of human health is also a critical objective of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), which is the federal government's blueprint for responding to oil spills and releases of hazardous substances, pollutants, or contaminants. On this basis, the EPA has broad authority to assess and, if warranted, mitigate vapor intrusion in residential and nonresidential settings arising from subsurface contamination by hazardous chemicals. If hazardous vapor-forming chemicals are present, the potential for human health risk from vapor intrusion should be evaluated throughout the cleanup life cycle (i.e., initial site assessment, site investigation, interim response actions,[7] final cleanup actions, and periodic reviews of the selected cleanup plan).[8]

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[3] Radon is a colorless, odorless, radioactive gas that is formed from the decay of radium, a radioactive element that occurs naturally in the soil and bedrock in many areas of the United States. Radon can also be emitted from certain uranium- or radium-containing products and wastes.

[4] A recent, registry-based epidemiological study (Forand et al. 2012) reported adverse birth outcomes (including cardiac defects) in areas in Endicott, New York with TCE-contaminated groundwater.

[5] Amendments to CERCLA include the Small Business Liability Relief and Brownfields Revitalization Act.

[6] Application of these statutory authorities to a particular situation generally entails site- and fact-specific analysis. In general, Regions should make decisions about use of these authorities and about intra-Regional coordination of staff and budgetary resources when addressing sites with potential concerns for vapor intrusion.

[7] The words "response action" or "response" are used generically in this guidance to include remedial and removal actions under CERCLA as amended and similar actions under RCRA as amended.

[8] EPA may need access to private property to conduct investigations, studies and cleanups pursuant to CERCLA and RCRA, as amended. The Superfund Amendments and Reauthorization Act of 1986 and RCRA explicitly grant EPA the authority to enter property for these purposes (EPA 1986, 1987, 2010a). EPA generally prefers to obtain access through consent. If consent is denied, however, EPA can use the judicial process or an administrative order to gain access. Application of legal doctrines to a particular access situation requires site- and fact-specific analysis.

1.3 Scope and Applicability of Document

The Final VI Guidance presents EPA's current recommendations for how to identify and consider key factors when assessing vapor intrusion, making risk management decisions, and implementing mitigation pertaining to this potential human exposure pathway. This guidance addresses both residential and nonresidential buildings that may be impacted by vapor intrusion from subsurface contamination.

The Final VI Guidance supersedes and replaces all Agency guidance documents addressing assessment and mitigation of the vapor intrusion pathway, including EPA's *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (EPA 2002c) ("Draft VI Guidance").

The Final VI Guidance is intended for use at any site[9] being evaluated by EPA pursuant to CERCLA or RCRA, EPA's brownfield grantees, or state agencies with delegated authority to implement CERCLA or RCRA where vapor intrusion may be of potential concern. EPA recommends consideration of the Final VI Guidance when:

- Making "Current Human Exposures Under Control" environmental indicator (EI) determinations at RCRA corrective action facilities (EPA 1999a, 2002b)[10] and National Priorities List (NPL) sites under CERCLA (EPA 2008b);
- Undertaking removal actions, remedial actions, pre-remedial investigations,[11] remedial investigations, and five-year reviews (FYRs)[12] under CERCLA; and
- Undertaking RCRA facility investigations and corrective actions and site investigations and cleanups at federal facilities and brownfield sites.

The broad concepts of this guidance generally may be appropriate when evaluating any of a large number and broad range of vapor-forming chemicals— described and identified in Section 3.1 and Appendix A—that potentially can provide subsurface sources for vapor intrusion into buildings. These chemicals include, for example, chlorinated hydrocarbons (CHCs), petroleum hydrocarbons, other types of both halogenated and non-halogenated volatile organic

[9] The term "site" is used generically in this guidance to represent areas of contamination managed in a cleanup project under CERCLA as amended, under RCRA as amended, at a federal facility, or pursuant to an EPA Brownfields grant.

[10] Also see http://www.epa.gov/osw/hazard/correctiveaction/eis/faqs.htm.

[11] The Hazard Ranking System (HRS) is the statutorily required method for identifying sites for placement on the NPL.

[12] There are additional, special considerations for CERCLA five-year reviews that are described in the companion OSWER Directive 9200.2-84 (EPA 2012d).

compounds (VOCs), elemental mercury, and radon when it arises from uranium- or radium-bearing solid wastes in the subsurface.[13]

This guidance document addresses risk management or exposure mitigation methods for indoor air contamination that arises from vapor intrusion from subsurface sources of these vapor-forming chemicals. It is not intended as a guide for assessing or mitigating indoor air exposures that arise solely from other sources (e.g., indoor use and storage of certain consumer products[14]).

The exposure route of general interest for vapor intrusion is inhalation of toxic vapors present in indoor air that have entered via soil gas entry from the subsurface.[15] Other human exposure routes that may warrant consideration during site investigations of subsurface contamination (e.g., ingestion of soil or water, dermal contact with soil or water, inhalation of particulate material, inhalation of vapors while outdoors, and inhalation of vapors while showering or washing with contaminated groundwater while indoors) are not addressed in this guidance document.

1.3.1 Applicability to Petroleum Hydrocarbons

The broad concepts of this guidance document are generally applicable to petroleum hydrocarbons. In particular, the approaches in the Final VI Guidance are recommended for evaluating the vapor intrusion pathway pursuant to CERCLA and RCRA for petroleum hydrocarbons that are mixed with CHCs or are the result of releases from sources other than Subtitle I underground storage tank (UST) systems. For petroleum hydrocarbons that arise from petroleum that has been released from Subtitle I UST systems, EPA has developed a companion to this Final VI Guidance, which provides information and guidance about how vapor intrusion should be assessed for petroleum hydrocarbons in these settings ("OUST Guidance") (EPA 2013d). The OUST guidance may also be useful in informing decisions about vapor intrusion and petroleum hydrocarbons at brownfield sites that are similar to a typical Subtitle I UST release.

Many petroleum hydrocarbons may naturally biodegrade in the vadose zone through the actions of microorganisms found naturally in soil. When oxygen supply from the atmosphere is sufficient, biodegradation of petroleum hydrocarbons can occur relatively quickly, will generally produce less harmful compounds, and can result in substantial attenuation of petroleum hydrocarbon vapors over relatively short distances in the vadose zone.

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[13] Radon emanating from natural geological materials may impact indoor air quality in occupied buildings. According to EPA estimates, inhalation of toxic radon decay products is the leading cause of lung cancer among non-smokers. For more information and EPA-recommended action levels for radon, see: http://www.epa.gov/radon/healthrisks/html.

[14] Indoor air in most buildings will contain detectable levels of a number of volatile compounds, whether or not the building overlies a subsurface source of vapor-forming chemicals (EPA 2011a). As discussed further in Section 2.5 of this document, these chemicals originate from indoor uses of chemical-containing products and from outdoor (ambient) air. EPA's indoor air quality program provides useful advice for control of indoor air exposures (see http://www.epa.gov/iaq/).

[15] In addition, certain hazardous chemicals (e.g., methane) can pose explosion hazards when they accumulate in confined spaces.

Numerous site-specific factors can influence the biodegradation rate of petroleum hydrocarbons and other biodegradable vapor-forming chemicals in the vadose zone. These factors include quantities, distribution, types, and mixtures of vapor-forming chemicals, which can differ substantially among sites where petroleum hydrocarbons are released to the subsurface environment. The Final VI Guidance allows site-specific observations of the effects of biodegradation to be considered in its approach for petroleum hydrocarbons (and any other biodegradable, vapor-forming chemical).

1.3.2 Applicability to Nonresidential Buildings

EPA's statutory authorities to protect human health (see Section 1.2) include mandates to protect the public and workers' health in nonresidential settings where hazardous vapors may be intruding into occupied buildings from vapor intrusion. As used in the Final VI Guidance, the phrase "nonresidential buildings" may include, but is not limited, to institutional buildings (e.g., schools, libraries, and hospitals); commercial buildings (e.g., hotels, office buildings, and retail establishments); and industrial buildings where vapor-forming chemicals may or may not be routinely used or stored.

Section 4.0 expands on EPA's recommended approach to evaluating and mitigating vapor intrusion in nonresidential buildings.

1.4 Additional Companion Documents and Technical Resources

Supplemental guides and technical support documents were developed to facilitate consideration of the recommendations in the Final VI Guidance. They are described in this section and can be found on OSWER's website about vapor intrusion (see Section 10.0 for citations and Web links).

1.4.1 Vapor Intrusion Screening Level Calculator

The Vapor Intrusion Screening Level (VISL) Calculator (2012c) is a recommended spreadsheet that:

(1) Identifies chemicals considered to be typically vapor-forming and known to pose a potential cancer risk or noncancer hazard through the inhalation pathway;

(2) Provides generally recommended screening-level concentrations for groundwater, near-source soil gas (exterior to buildings), sub-slab soil gas, and indoor air based upon default residential or nonresidential exposure scenarios, a target cancer risk level of one per million (10^{-6}), and a target hazard quotient of one for potential non-cancer effects; and

(3) Facilitates calculation of site-specific screening levels based on user-defined target risk levels, exposure scenarios, and semi-site-specific attenuation factors.

The VISL Calculator can be used in evaluating whether the vapor intrusion pathway has the potential to pose a health concern by helping to:

(1) Identify whether chemicals that can pose a risk through vapor intrusion are present;

(2) Determine if those chemicals are potentially present at explosive levels;

(3) Compare subsurface or indoor data against recommended screening levels provided in the VISL Calculator; and

(4) Prioritize buildings and sites for investigation and response action.

The recommended screening-level concentrations in the spreadsheet are calculated using the recommended approaches in existing EPA health risk assessment guidance and are based on current understanding of the vapor intrusion pathway. EPA intends to periodically update the VISL Calculator to incorporate new toxicity or chemical property information that becomes available.

1.4.2 Superfund Five-year Review Guidance

Section 121 of CERCLA requires that remedial actions that result in any hazardous substances, pollutants, or contaminants remaining at the site be re-evaluated every five years to ensure that the remedy is and will continue to be protective of human health and the environment. OSWER Directive 9200.2-84 (*Assessing Protectiveness at Sites for Vapor Intrusion: Supplemental Guidance to the Comprehensive Five-Year Review Guidance* (EPA 2012d)) provides a recommended framework for considering vapor intrusion while evaluating remedy protectiveness in the context of the Superfund FYR process (even if vapor intrusion was not addressed as part of the original remedial action).

1.4.3 Technical Support Documents

Technical information pertaining to vapor intrusion has also been prepared to support development of the technical approaches and policy recommendations in the Final VI Guidance and OUST Guidance. Key supporting documents include:

Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion (EPA 2011a): This externally peer-reviewed, technical report presents (1) a summary of indoor air studies that measured background concentrations of VOCs in the indoor air of thousands of North American residences and an evaluation and (2) compilation of the statistical information reported in these studies. The objective of this compilation is to illustrate the ranges and variability of VOC concentrations in indoor air during the study period (1990-2005), resulting from sources other than vapor intrusion.

EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings (EPA 2012a): This externally peer-reviewed report presents technical information about sites in the U.S. that have been investigated for vapor intrusion. The primary focus of the report is the evaluation of concentrations of chlorinated VOCs in and underneath residential buildings based upon the EPA's vapor intrusion database as of 2010. This report provides the technical basis for the generic and semi-site-specific attenuation factors recommended in the Final VI Guidance to calculate vapor intrusion screening levels (see Section 6.5 and Appendix B).

Conceptual Model Scenarios for the Vapor Intrusion Pathway (EPA 2012b): This externally peer-reviewed report provides simplified simulation examples to illustrate graphically how subsurface conditions and building-specific characteristics determine: (1) the distribution of vapor-forming chemicals in the subsurface; and (2) the indoor air concentration relative to a source concentration. It was prepared to help environmental practitioners gain insights into the processes and variables involved in the vapor intrusion pathway and to provide a theoretical framework with which to draw inferences about and better understand the complex vapor fate and transport conditions typically encountered at actual, contaminated sites.

Sampling and Analysis Methods for Vapor Intrusion Investigations (EPA 2013c): This report provides a technical description of the most commonly implemented and generally accepted techniques for collecting samples of indoor air, outdoor air, soil gas or sub-slab gas for analysis of VOCs or other vapor-forming chemicals that might be of concern for the vapor intrusion pathway. It was prepared to assist site managers and risk assessors select the most appropriate sampling devices and analytical methods to employ during site-specific investigations.

Technical Basis for the Selection, Design, Installation and Operation & Maintenance of Vapor Intrusion Mitigation Systems (EPA 2013b): This report provides a technical description of the most commonly implemented and generally accepted methods for mitigation of vapor intrusion in buildings and provides information about their design and construction.

All of these tools and documents, as well as others, can be found at http://www.epa.gov/oswer/vaporintrusion, a website developed to support the development of the Final VI Guidance and enhance public communication about the topic. This website also allows certain sections of this guidance to be more dynamic and facilitates updates to information.

Technical documents intended to facilitate consideration of the recommendations in the OUST Guidance can be found at http://www.epa.gov/oust/cat/pvi/.

1.5 Historical Context

To help assess the subsurface vapor intrusion pathway, the Office of Solid Waste and Emergency Response (OSWER) released in November 2002 for comment EPA's Draft VI Guidance, which presents EPA's technical and policy recommendations for evaluating subsurface vapor intrusion, based on the understanding of vapor intrusion at that time (EPA 2002c). The Final VI Guidance supersedes and replaces the Draft VI Guidance.

Since the Draft VI Guidance was released, EPA's knowledge of and experience with assessment and mitigation of the vapor intrusion pathway has increased considerably, leading to an improved understanding of and enhanced approaches for evaluating and managing vapor intrusion. In December 2009, the OIG made recommendations regarding EPA's Draft VI

Guidance, which are documented in the evaluation report *Lack of Final Guidance on Vapor Intrusion Impedes Efforts to Address Indoor Air Risks* (Report No. 10-P-042; EPA 2009a). Among other things, the OIG recommended that the final guidance incorporate:

- Updated toxicity values.
- A recommendation(s) to use multiple lines of evidence in evaluating and making decisions about risks from vapor intrusion.
- How risks from petroleum hydrocarbon vapors should be addressed.
- How the guidance applies to Superfund FYRs.
- When or whether preemptive mitigation is appropriate.
- Operations, maintenance, and termination of mitigation systems.
- When institutional controls (ICs) and deed restrictions are appropriate.

In its response letter dated March 11, 2010, OSWER generally agreed with OIG's recommendations to finalize guidance on vapor intrusion. In addition, the OIG recommended that EPA identify and publicly report the portions of its Draft VI Guidance that remain valid and the portions that should be updated.[16]

The Final VI Guidance and the companion documents identified in Sections 1.3 and 1.4 fulfill EPA's commitment to issue final vapor intrusion guidance that addresses all of OIG's recommendations. Table 1-1 identifies specific guidance updates prepared by EPA in response to OIG's specific recommendations. Table 1-2 describes additional guidance updates identified and publicly announced by EPA (EPA 2010b).

[16] OSWER carried out this recommendation by issuing a memorandum in August 2010 (EPA 2010b), a copy of which is included on OSWER's vapor intrusion website at http://www.epa.gov/oswer/vaporintrusion/documents/review_of_2002_draft_vi_guidance_final.pdf. The guidance reflected in this memorandum is incorporated in the Final VI Guidance.

TABLE 1-1
DIRECTORY TO UPDATES IN EPA'S FINAL VAPOR INTRUSION GUIDANCE ADDRESSING RECOMMENDATIONS OF EPA OFFICE OF INSPECTOR GENERAL (EPA 2009)

Topics to Be Addressed	Location Within This Guidance Document	Companion Document(s)
Update toxicity values		*VISL Calculator* (EPA 2012c)
Use of multiple lines of evidence in evaluating and making decisions about risks from vapor intrusion	Sections 2, 5, and 6	
How risks from petroleum hydrocarbon vapors should be addressed	Section 1.3.1	*Guidance for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (EPA 2013d)
How the guidance applies to Superfund FYRs		*Assessing Protectiveness at Sites for Vapor Intrusion: Supplemental Guidance to the Comprehensive Five-Year Review Guidance* (EPA 2012d)
When or whether preemptive mitigation/early action is appropriate	Sections 3.4 and 9.0	
Operations and maintenance of mitigation systems	Section 8.3	
Termination of mitigation systems	Section 8.7	
When ICs and deed restrictions are appropriate.	Section 8.6	

TABLE 1-2
DIRECTORY TO ADDITIONAL UPDATES IN EPA'S FINAL VAPOR INTRUSION GUIDANCE PUBLICLY IDENTIFIED BY OSWER (EPA 2010A)

Topics to Be Updated, Including References to the Draft VI Guidance	Location Within This Guidance Document	Companion Document(s)
Updated a few chemical-specific physical parameters used for identifying the vapor-forming chemicals of concern.	Appendix A	VISL Calculator (EPA 2012c)
Updated the toxicity-based criteria in Table D-1 in the draft guidance.	Appendix A	VISL Calculator (EPA 2012c)
Observation-based conservative attenuation factors have been updated with a larger database. The generic attenuation factor for external soil gas has been updated, as well as the Reliability Assessment, using the newer available data.	Section 6.5.2 and Appendix B	*U.S. EPA's Vapor Intrusion Database: Evaluation of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012a)
Observational data since 2002 indicates that the "single line of evidence" approach with site-estimated attenuation factors is generally not appropriate for external soil gas samples.	Section 6.4.4 and Appendix B	*Sampling and Analysis Methods for Vapor Intrusion Investigations* (EPA 2013c)
Experiences since 2002 illustrate the value of collecting indoor air samples earlier in the investigations. The "indoor lair last" approach has been updated that will allow more flexibility in the sequencing of subsurface and interior/indoor sample collection.	Sections 6.3.4 and 6.3.6	
The portions addressing background contamination has been updated. EPA also updated with more specific methodologies for evaluating and/or decision-making and managing background contamination.	Section 6.3.5	
The portion of the guidance focusing on testing indoor air has been updated to allow more flexibility in the duration of sampling to take advantage of other sampling durations and methods.	Section 6.4.1	*Sampling and Analysis Methods for Vapor Intrusion Investigations* (EPA 2013c)
The Draft VI Guidance allows site-specific decisions to be made based on indoor air concentrations in a relatively few representative buildings. This portion of the guidance has been updated to increase the confidence that the approach fully addresses building-by-building variability.	Section 9	
Updated and expanded the community involvement guidance to be more specific to vapor intrusion sites, including guidelines for effective risk communication and available resources, outreach products and tools for outreach.	Section 10	

Since EPA's release of its Draft VI Guidance in 2002, other federal agencies with responsibilities and obligations for environmental cleanup or for response to reports of vapor intrusion (e.g., ATSDR 2008; DoD 2009; DoN 2011a; USPS 2009) have developed vapor intrusion guides for their respective programs. In addition:

- A number of state agencies involved with environmental quality or public health protection have developed vapor intrusion guides for their programs, which they may continue to implement under their respective statutory authorities (e.g., see ASTSWMO [2009], a compilation).
- The Interstate Technology & Regulatory Council (ITRC), a state-led coalition of environmental regulatory professionals, prepared a two-volume guideline for assessing the vapor intrusion pathway (ITRC 2007ab).

EPA has considered these guides in developing the Final VI Guidance. EPA believes that States will find the Final VI Guidance useful.

1.6 Public Involvement in Developing Vapor Intrusion Guidance

On November 29, 2002, EPA published a notice in the *Federal Register* (67 FR 71169) announcing and soliciting comment on its Draft VI Guidance. Over the next decade, EPA continued to gather information and learn more about vapor intrusion, in part by convening periodic forums where practitioners, regulated parties, and regulators could discuss the emerging science and engineering pertaining to vapor intrusion assessment and mitigation. In addition, on March 17, 2011, EPA published a notice in the *Federal Register* (76 FR 14660) re-opening the docket and soliciting additional comment on its development efforts for the Final VI Guidance. The docket was re-opened again in March 2012 to receive comments about specific technical documents that were prepared to support development of this guidance document; these technical documents are listed in Section 1.4. In developing the Final VI Guidance, EPA considered all public comments and input received during the past decade.

EPA also decided to proactively engage communities beyond the traditional outreach practices, especially environmental justice communities and communities subject to multiple stressors.[17] Aspects of this engagement have included:

- Conducting public listening sessions in communities impacted by vapor intrusion to solicit input on developing the Final VI Guidance.
- Using Internet sites and other communication tools to update stakeholders on the progress of developing the Final VI Guidance.

Table 1-3 identifies specific vapor intrusion topics that have received substantive public comment as a result of EPA's outreach efforts.

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[17] For more information about the Community Engagement Initiative visit: http://www.epa.gov/oswer/engagementinitiative/

TABLE 1-3
VAPOR INTRUSION TOPICS RECEIVING SUBSTANTIVE PUBLIC COMMENT

Topics	Location Within This Guidance Document	Companion Document(s)
Applicability to petroleum hydrocarbons	Section 1.3.1	*Guidance for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* (EPA 2013d)
Applicability to nonresidential buildings	Sections 1.3.2 and 4.0	
Conditions warranting prompt action and short-term response actions	Sections 5.2 and 8.2.1	
Planning investigations and applying data quality objectives	Section 6.2 and Appendix C	
Sampling and monitoring methods for indoor air	Section 6.4.1	*Sampling and Analysis Methods for Vapor Intrusion Investigations* (EPA 2013c)
Attenuation factors and risk-based screening	Section 6.5 and Appendix B	*U.S. EPA's Vapor Intrusion Database: Evaluation of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012c)
Semi-site-specific screening and application of mathematical models	Sections 6.5 and 6.6	
Use of conceptual site models and multiple lines of evidence in evaluating risks posed by vapor intrusion	Sections 2, 5.4, 6.3, and 7	
Use of institutional controls for building mitigation	Section 8.6	
Monitoring and termination of mitigation systems	Sections 8.4 and 8.7	
Risk communication	Section 10	

1.7 Organization

The next nine sections of this guidance document are as follows:

- Section 2.0 Conceptual Model of Vapor Intrusion further describes vapor intrusion and identifies many of the variables that influence vapor migration in the vadose zone and soil gas entry into buildings.

- Section 3.0 Overview of Vapor Intrusion Guide provides an overview of this guidance document and the general framework of the vapor intrusion assessment and mitigation process.

- Section 4.0 Considerations for Nonresidential Buildings provides guidance regarding EPA roles, responsibilities, and risk management decision-making in workplace settings, including those (e.g., manufacturing facilities) where workers handle hazardous chemicals similar to or different from those contaminating the subsurface.

- Section 5.0 Preliminary Analysis of Vapor Intrusion provides technical and policy guidance for situations where only limited site-specific sampling data may be available (e.g., initial site assessment).

- Section 6.0 Detailed Investigation of Vapor Intrusion provides technical and policy guidance for conducting site-specific vapor intrusion assessments emphasizing multiple lines of evidence.

- Section 7.0 Risk Management Framework provides general recommendations about risk-informed decision-making pertaining to vapor intrusion.

- Section 8.0 Building Mitigation and Subsurface Remediation provides technical and policy guidance for mitigating vapor intrusion and describes how subsurface vapor source remediation and other final cleanup actions are combined with engineering exposure controls to ensure protection of human health.

- Section 9.0 Preemptive Mitigation/Early Action discusses statutes and considerations affecting the selection and implementation of building mitigation as an early action for vapor intrusion.

- Section 10.0 Planning Guide for Community Involvement provides guidance and describes available resources for engaging affected communities and communicating risk-related information.

This guidance document concludes with Section 11.0, Citations and References, and four supporting appendices:

- Appendix A: Chemicals of Potential Concern for Vapor Intrusion.

- Appendix B: Generic Attenuation Factors Used to Develop Screening Levels.

- Appendix C: Data Quality Assurance Considerations.
- Appendix D: Calculating Vapor Source Concentration from Groundwater Data.

2.0 CONCEPTUAL MODEL OF VAPOR INTRUSION

This section presents a conceptual model of vapor intrusion, borrowing from published depictions (EPA 2008a; EPA 2012b; ITRC 2007a; McAlary et al. 2011; DoD 2009). It identifies and describes many of the lines of evidence pertinent to evaluating vapor intrusion.[18] It concludes with several general observations that may assist practitioners when conducting detailed vapor intrusion investigations.

Vapor intrusion is a potential human exposure pathway ─ a way that people may come into contact with environmental contaminants while performing their day-to-day indoor activities. Figure 2-1 summarizes the vapor intrusion pathway.

The exposure route of general interest for vapor intrusion is inhalation of toxic vapors present in indoor air. As noted previously, methane and certain other volatile chemicals can also pose explosion hazards when they accumulate in confined spaces.

Three conditions must exist for hazardous vapors to reach the interior of buildings from the subsurface environment underneath or near a building:

1. A source of hazardous vapors must be present in the soil or in groundwater underneath or near a building.

2. Vapors must form and have a pathway along which to migrate toward the building.

3. Entry routes must exist for the vapors to enter the building and driving forces must exist to draw the vapors into the building.

If these three conditions are present, the vapor intrusion pathway is referred to as "complete." These three conditions are further discussed in the next three subsections. Practitioners are encouraged to refer to quantitative discussions of these subjects, which are provided in the user's guide to the Johnson & Ettinger model (EPA 2013e) and *Conceptual Model Scenarios for the Vapor Intrusion Pathway* (EPA 2012b).

Knowledge of potential vapor sources and vapor fate and transport mechanisms is essential for interpreting the data collected during a site-specific investigation of vapor intrusion. Knowledge of the factors that influence the vapor intrusion pathway is also invaluable for identifying, prioritizing, and sequencing data collection activities, which allows a phased and efficient overall investigation plan to be developed.

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[18] In general, a conceptual site model integrates all lines of site-specific evidence into a three-dimensional conceptualization of site conditions that includes contaminant sources, release mechanisms, vapor migration pathways, and potential receptors. Section 5.4 provides additional information about developing conceptual site models.

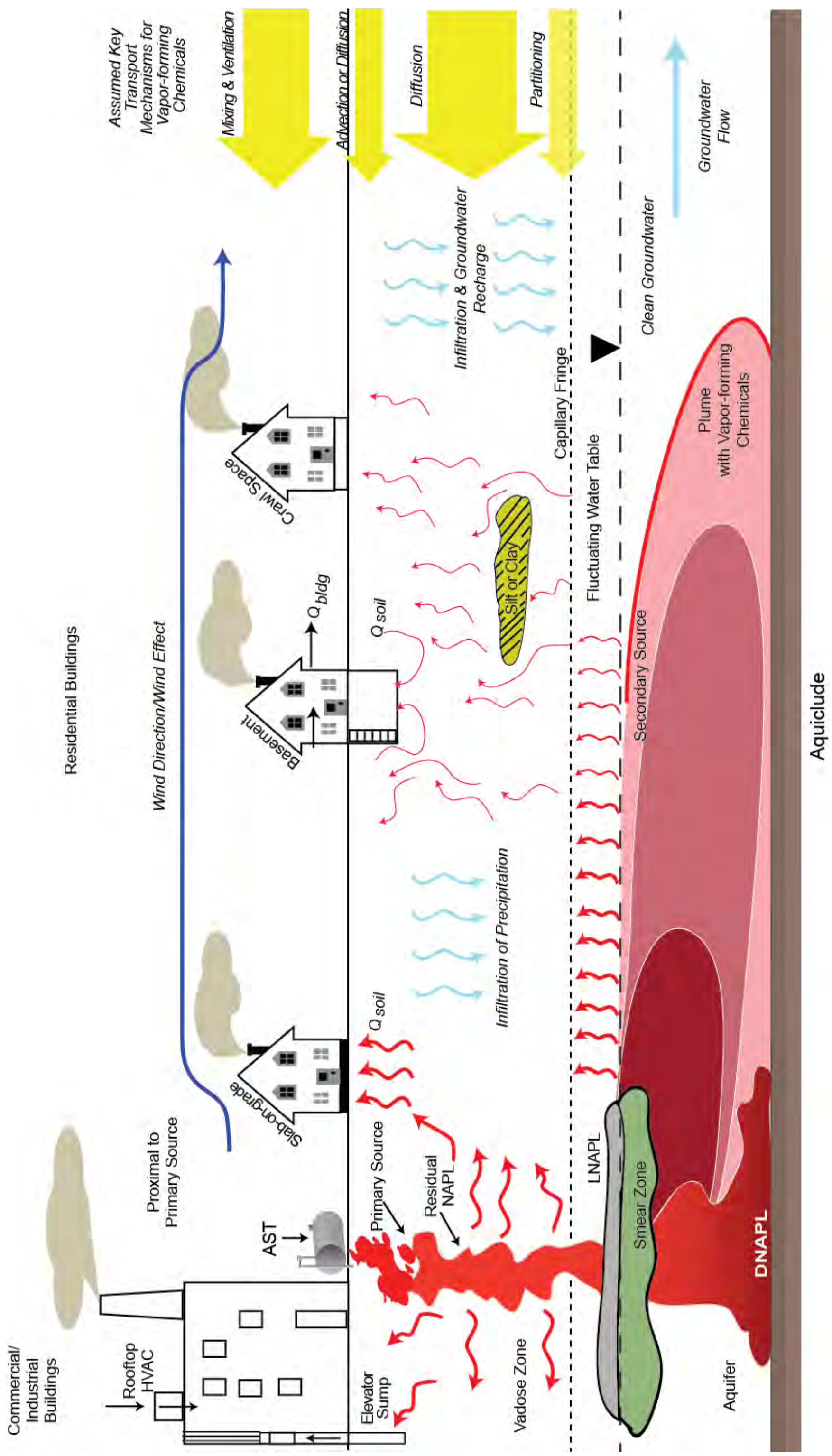

Figure 2-1 Illustration of Conceptual Model of Vapor Intrusion
Note: Q_{soil} represents soil gas entry; Q_{bldg} represents building ventilation.

The human populations of primary interest are individuals living or working in, or otherwise occupying a building subject to vapor intrusion. All types of buildings are potentially vulnerable to vapor intrusion. This includes residential buildings (e.g., single-family homes, trailers, multi-unit apartments and condominiums), commercial workplaces (e.g., office buildings, retail establishments), industrial facilities (e.g., manufacturing plants), and educational and recreational buildings (e.g., schools and gyms). Vapor intrusion can occur in buildings with any foundation type (e.g., basement, crawl space, slab-on-grade).

At sites with existing buildings, there are concerns about whether vapor intrusion may pose an unacceptable health risk to current occupants or potential for explosion hazard. EPA recommends that vapor intrusion should also be evaluated for reasonably expected future land use conditions, including new building construction and new uses and occupants for the uninhabited buildings.

2.1 Subsurface Vapor Sources

The original source(s) of subsurface contamination may include leaking tanks (above or below ground), sewer lines[19] and pipelines, floor drains, landfills and other land disposal management units,[20] fire-training areas, spills, and discharge areas. The resulting subsurface contamination may be comprised of non-aqueous-phase liquids (NAPLs) (e.g., solvents, petroleum-related products, such as gasoline) and contaminated soil. These are often referred to as the source zone(s). In addition, primary vapor releases from pipelines leaking chemical vapors can serve as a source of contamination. Groundwater flowing through the source zone(s) can become contaminated, migrate away, and in turn become a (secondary or derivative) source of contaminant vapors at locations distant from the source zone.

Regardless of source type, soil vapor concentrations emanating from a subsurface source attenuate, or decrease, as the volatile chemicals move from the source through the soil and into indoor air. If soil vapor monitoring data at a given site are not consistent with this trend, practitioners should consider the possible existence of multiple sources at the site and the possibility of bias or error in the sampling techniques.

Contaminants in soil, NAPLs, and groundwater can become sources for vapor intrusion if they are likely to volatilize under normal temperature and pressure conditions and are toxic when inhaled. Water solubility is also a factor for chemicals in source zones that come into contact with migrating groundwater. Common classes of chemicals of concern for vapor intrusion that exhibit the foregoing characteristics are VOCs, such as tetrachloroethene (PCE), trichloroethene (TCE), vinyl chloride (VC), carbon tetrachloride, and benzene, toluene,

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[19] Historically, sanitary sewers and septic tanks have been common disposal points for aqueous and chemical wastes from commercial and industrial operations. Contaminated water, NAPL, and VOC vapors can leak from sewer lines through cracks, joints, or breaks. A study of solvent contamination in California arising from dry cleaning operations concluded, "Where a source investigation has been done in connection with PCE contamination, the … data strongly indicate that leakage through the sewer lines is the major avenue through which PCE is introduced to the subsurface." (Izzo 1992).

[20] EPA has also published *Guidance for Evaluating Landfill Gas Emissions from Closed or Abandoned Facilities* (EPA 2005), which provides procedures and a set of tools for evaluating landfill gas emissions to ambient air and soil gas migration due to pressure gradients.

ethylbenzene and xylenes (collectively, BTEX). Other compounds that are not as volatile, but that may be cause for concern, are some polychlorinated biphenyl congeners and elemental mercury, a dense NAPL (DNAPL).

Landfill gases, such as methane and hydrogen sulfide, also can be associated with the vapor intrusion pathway for buildings located near current or former landfills or other degrading wastes or near degrading petroleum leaked from USTs. These gases are actively produced as a result of biodegradation processes. Methane can also be associated with the vapor intrusion pathway for buildings located near leaks from underground transmission lines for natural gas.

Properties with potential contamination by vapor-forming chemicals can be found in many industrial and commercial areas. These properties include current and former manufacturing and chemical processing plants, warehouses, landfills and other land disposal units, coal gasification plants, chemical handling or transfer facilities and areas (e.g., train yards), dry cleaners, and retail fueling outlets (also known as gas stations). Use, storage, or transport of chemicals at these facilities may have resulted in a release of vapor-forming chemicals to the environment creating the potential for future vapor intrusion issues. In addition to industrial and commercial activities, roadside dumping, pesticide spraying, or even disposal of household chemicals via a septic field may also release volatile contaminants to the subsurface environment.

The primary contamination source need not, however, be on the property of interest to pose a vapor intrusion problem.[21] The primary source(s) of vapor intrusion (e.g., contaminated soil, or buried drums) may be present on a neighboring property or on a property some distance away. Even "greenspace" properties that have not previously been occupied or developed may contain contamination by vapor-forming chemicals due to migrating plumes of contaminated groundwater or migrating soil gas. Therefore, EPA recommends that the potential for vapor intrusion be considered at all properties being considered for redevelopment or proximate to industrial and commercial use areas (EPA 2008a).

2.2 Subsurface Vapor Migration

At many sites, the vapor source in soil or groundwater is not in contact with the bottom of the subject building. Under these circumstances, a volatile chemical that is present in a source zone or groundwater must volatilize from the source medium and enter the pore space around and between the subsurface soil particles in the soil column above the groundwater table, which is called the unsaturated soil zone or vadose zone. If the vapor source is in the vadose zone, the vapors have the potential to migrate radially in all directions from the source via diffusion (i.e., upward toward the atmosphere, laterally outward, and downward toward the water table, which may eventually lead to groundwater contamination). Diffusion, which is caused by the random motion of molecules, affects the distribution of soil vapors when there are spatial differences in

[21] Depending on the geology and amount and form of contamination in the source zone(s), contaminated groundwater plumes can be long and narrow and can flow beneath a property located a mile or more away from the primary source. Soil gas plumes tend to extend in both lateral directions and can be larger in lateral extent relative to groundwater plumes.

chemical concentrations in the soil gas. The net direction of diffusive transport is toward the direction of lower concentrations.

Advection occurs in the vadose zone when there is bulk movement of soil gas induced by spatial differences in soil gas pressure. The direction of advective vapor transport is always toward the direction of lower air pressure. Advection is generally expected to occur in the vicinity of buildings, because differences in temperature between the building interior and the subsurface environment or the operation of combustion units or fans within the building can create driving forces for soil gas entry (See Section 2.3). Advection may also occur near the ground surface due to fluctuations in barometric (atmospheric) pressure, which can either release soil gas into the atmosphere or introduce ambient air into the subsurface environment; the latter process may be important in oxygenating surface soil horizons. Advection may be hindered where extensive surface barriers, such as asphalt, concrete, or frozen soil are present.

Vapors also can migrate via advection (and diffusion) along a preferential subsurface pathway, such as a utility corridor or more porous layers of soil, or beneath surface barriers that limit the direction(s) of vapor migration, such as frozen ground or asphalt.

Vapor migration in the vadose zone can be impeded by several factors, including high soil moisture, low-permeability (generally fine-grained) soil, and biodegradation:

- High moisture levels in the vadose zone can significantly reduce the effective rate of diffusive transport, owing to the substantially smaller diffusion coefficient of vapor-forming chemicals in water compared to air. Where impervious ground covers are absent, soil cores taken external to building structures can reasonably be expected to show greater soil moisture than underneath buildings, particularly after episodes of precipitation and infiltration. Fluctuations in the elevation of the groundwater table can also contribute to temporal changes in soil moisture profiles, in addition to changing the thickness of the vadose zone.

- A low-permeability layer in the vadose zone, particularly one with high moisture content or perched water, may impede or prevent upward migration of vapors from deeper sources in the vadose zone.[22] In some cases, soil or rock can impose sufficient resistance to vapor migration to make the vapor intrusion pathway insignificant, providing the geologic features are laterally extensive over distances that are large compared to the size of the building(s) or the extent of subsurface contamination with vapor-forming chemicals.

- Some biodegradable chemicals may experience reductions in their vapor concentrations in biologically active vadose zones. In some cases, biodegradation may make the vapor intrusion pathway insignificant. Depending upon the potential for oxygen to migrate into the subsurface from the ambient air, such biodegradation may be anaerobic or aerobic.

[22] Low-permeability layer(s) overlying contaminated groundwater (i.e., “aquicludes”) can, likewise, impede the flux of vapors from the contaminated plume to the vadose zone. The aquiclude shown at the base of Figure 2-1 would not impede the flux of vapors from the contaminated plume to the vadose zone, however, because the aquiclude is below both. It would impede vapor flux from any additional contaminated plume located below it.

There is uncertainty regarding whether and to what extent oxygen levels will typically be different underneath a building compared to locations outside the building footprint where impervious covers are absent and the ground surface is in contact with the atmosphere. Significant characterization of the soil may, therefore, be required to demonstrate the extent, if any, to which these processes act as a barrier to vapor transport at specific sites, which may entail intensive testing or investigative methods that are very different from the sampling and analysis techniques for indoor air and soil gas. Such characterization should also consider the possibility that biodegradation may result in the formation of by-products that are potentially hazardous (e.g., methane, vinyl chloride from PCE or TCE).

If the vapor-forming chemicals are dissolved in groundwater at the groundwater table (i.e., volatile chemicals are in the uppermost reaches of an unconfined – "water table" – aquifer), fluctuations in the water table will tend to transport the volatile chemicals upward (during periods of rising water table) or expose impacted water above the water table to soil gas (during periods of falling water table). The latter will facilitate the episodic formation of vapors in the vadose zone. Rising water tables also will bring the vapor source closer to the building(s).

If vapor-forming chemicals are not present in the upper reaches of the groundwater table (e.g., due to the presence of an overlying zone of clean water from recharge; i.e., "fresh water lens"),[23] vapor transport to the overlying vadose zone will be impeded due to the slower diffusion of volatile chemicals in water than in soil gas.

2.3 Driving Forces and Entry Routes into Buildings

The distribution and magnitude of vapor concentrations immediately beneath a building are expected to reflect the interplay between vapor transport toward the building (via diffusion and advection) in the vadose zone and vapor withdrawal due to soil gas entry into the building (in the case where the building is under-pressurized), which may be spatially and temporally variable. Likewise, soil vapor may become contaminated as a result of over-pressurized buildings forcing contaminated indoor air through openings in the foundation into nearby soil.

As mentioned in Section 2.2, advection in the vadose zone can arise in the vicinity of buildings whenever there is a differential between the air pressure within a building and the subsurface environment. The air pressure within a building can be lower (or higher) than in the subsurface due to:

- Temperature differences between indoor and subsurface locations (e.g., the winter-time "stack effect," when buildings are commonly heated, leading to convection cells driven

[23] Infiltrating precipitation is important in recharging aquifers with fresh water, as well as in wetting vadose zone soils. At locations distant from "source zones," infiltrated water that reaches the upper surface of a plume of contaminated groundwater (i.e., recharges groundwater) in an unconfined aquifer will tend to dilute concentrations of vapor-forming substances and form a lens of relatively "clean" water at the groundwater table, which will overlie the plume. Because diffusion of dissolved-phase volatile chemicals will tend to control the mass transfer of vapors into the soil gas at the groundwater table, the presence of a lens of clean water overlying a plume will tend to impede vapor flux to the vadose zone. This condition is less likely to occur where fluctuations of the groundwater table are large, relative to local recharge, and would not generally be expected in arid climates.

by heated air that rises to upper levels and leaks through roofs and upper-floor windows).

- The operation of mechanical devices, such as exhaust fans for ventilation, air conditioners, and clothes dryers, with vents to the outdoors.
- The operation of combustion devices that vent exhaust gases to the outside, such as fireplaces and furnaces.
- Wind load on the building walls.

Even small pressure differentials may cause advective flow of gas into or out of the building through pores, cracks, or openings in the building floor or basement walls.[24]

There also may be preferential soil gas flow through granular fill underneath a building, especially in locations where the gas permeability of the surrounding soil is low. Where granular materials have differentially settled, air voids (also highly permeable to soil gas flow) may form beneath the foundation. Utility penetrations and other conduits may be connected to the granular fill, accentuating the potential pathway for soil gas entry into a building. Adding to the complexity, pressure differentials caused by wind flows conceivably could create a cross-flow underneath the foundation, particularly where granular fill is also present underneath a building, which may episodically dilute vapor concentrations in the building vicinity.

Several factors can influence the potential indoor air concentration arising from vapor intrusion. Building ventilation, whether mechanical or natural, may serve to reduce the indoor air concentrations arising from vapor intrusion.[25] Mechanical ventilation may be provided by attic and other exhaust fans or, in the case of larger (e.g., commercial or industrial) buildings, heating or cooling systems that draw outdoor air into the building. Natural ventilation may occur through open windows, doors and attics, openings along the perimeters of windows and doors, and cracks in walls and ceilings.

In buildings that are mechanically ventilated, vapors intruding from the subsurface will tend to be distributed and mixed throughout the indoor air. Mixing can be expected to be incomplete as a general rule. For example, rooms with perforations through the foundation (e.g., bathrooms or utility rooms) tend to have greater concentrations of vapor-forming chemicals in air compared to

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[24] As a result of the construction of foundation walls and floor slabs, a perimeter crack (i.e., space between the floor slab and walls) may be created and serve as an entry location for soil vapors. This perimeter crack is often obscured by wall coverings, and may not be accessible for inspection or direct testing. Vapors have been observed to migrate through what appears to be intact concrete floors and walls, which may, in fact, have small unobserved fractures or porous areas from improper curing. In addition, conduits may be present to facilitate soil gas entry into buildings. These conduits may include utility (e.g., sewer, water, or electrical) penetrations and floor drains, which can be considered preferential (structural) pathways. Although floor drains are designed to allow water to drain away from the building, they are usually not designed or constructed to eliminate soil gas entry.

[25] Ventilation is usually described in terms of air exchanges (or changes) per hour (ACH). Values for residential air exchange rates are typically on the order of approximately 0.18 to 1.26 ACH (EPA 2011b, see Table 19-24 therein, 10^{th} and 90^{th} percentiles). Values for non-residential buildings are highly-dependent upon building use and can range widely (on the order of approximately 0.3 to 4.1 ACH) (EPA 2011b, see Table 19-27 therein, 10^{th} and 90^{th} percentiles).

rooms that do not. Generally, basements can reasonably be expected to exhibit greater vapor concentrations than upper occupied levels.

Buildings constructed over a crawl space with a dirt floor may benefit from the dilution of soil gas by any ventilation of crawl space air, but would not have the impedance to vapor intrusion that concrete slabs can provide. Trailers enclosed at the bottom by a skirt are expected to have greater potential for vapor intrusion than would non-enclosed trailers. Wind movement between the ground surface and the bottom of the non-enclosed trailer would tend to minimize vapor buildup and associated potential for vapor intrusion. Similarly, the existence of underground parking for a multi-story building (or other modifications to the foundation that enhance subsurface ventilation) would tend to minimize the potential for vapor intrusion and should be considered in the vapor intrusion evaluation.

2.4 Conceptual Model Scenarios

Based upon the foregoing conceptual model, numerous factors can influence the potential indoor air concentration arising from vapor intrusion. EPA, therefore, generally recommends collecting, evaluating, and weighing multiple lines of evidence to characterize the vapor intrusion pathway. Some of these significant factors are illustrated in Figure 2-2.

The document *Conceptual Model Scenarios for the Vapor Intrusion Pathway* (EPA 2012b) provides simplified simulation examples to illustrate graphically how several of the subsurface and building-specific factors work together to determine the distribution of volatile contaminants in the subsurface and the indoor air concentration relative to a source concentration. The conceptual model scenarios document offers insights into the factors influencing the vapor intrusion pathway. It provides a theoretical framework with which to draw inferences about and better understand the complex vapor fate and transport conditions typically encountered at actual, non-idealized contaminated sites. The following general observations can be made from these simplified simulation examples, and may be useful when considering the vapor intrusion pathway at a particular site:

- The horizontal and vertical distance over which vapors may migrate in the subsurface depends on the source concentration, source depth, soil matrix properties (e.g., porosity and moisture content), and time since the release occurred. Months or years may be required to fully develop vapor distributions in the vadose zone at sites with deep vapor sources or with impedances to vapor migration arising from hydrologic or geologic conditions.

- Vapor concentrations in the subsurface may not be uniform in sub-slab soil gas or in soil gas at similar depths exterior to the building of interest. Therefore, vapor concentration at exterior locations (i.e., outside a building's footprint) may be substantially different from the concentration underneath the building (e.g., the sub-slab concentration), depending on site-specific conditions and the location and depth of the exterior soil gas sample.

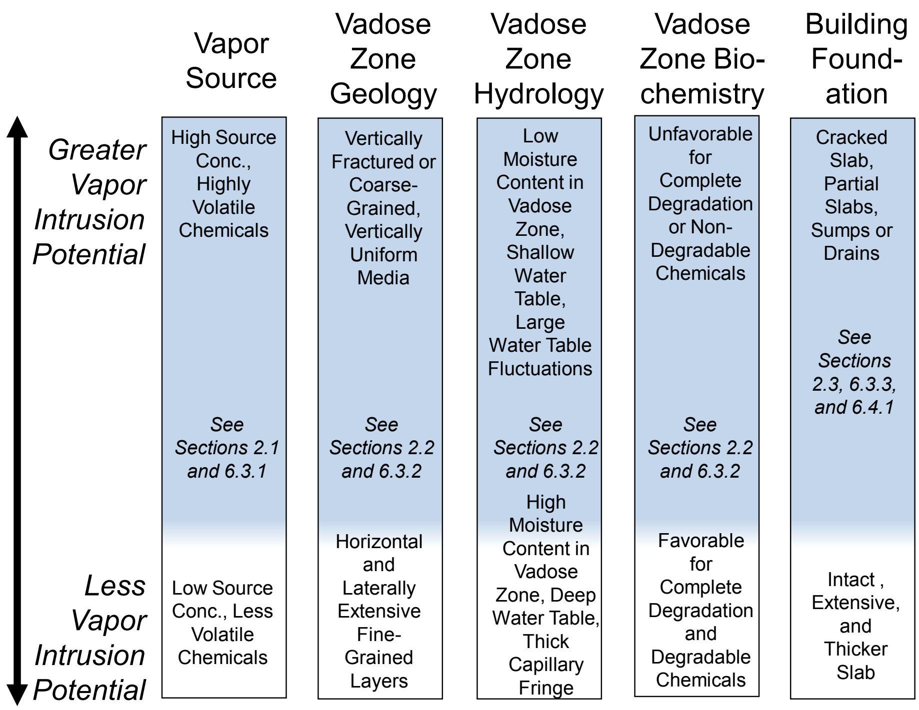

Figure 2-2 Some Factors that Affect Vapor Intrusion

- Simulations assuming an idealized, constructed ground cover suggest that shallow soil gas concentrations can be greater under low-permeability ground covers than under soil open to the atmosphere.
- The soil gas distribution beneath a building is not the only factor that determines the indoor air concentration. The indoor air concentration is also influenced by building conditions, including the presence of openings (e.g., cracks, utility penetrations) in the foundation, building pressurization, and the air exchange rate.
- Advective flow into buildings occurs predominantly near cracks and openings in the foundation slab and may affect the distribution of vapor-forming chemicals directly beneath the structure. Heterogeneities in the permeability of geologic materials and backfill, along with wind effects and building and atmospheric pressure temporal variation, may also contribute to the spatial and temporal variability of vapor concentrations in sub-slab soil gas and indoor air.
- Subsurface heterogeneities in site geology, such as layering and moisture content, influence the extent and rate of vapor migration from a contaminant source to overlying or adjacent buildings.
- The soil gas distribution of aerobically biodegradable chemicals (e.g., BTEX) can be significantly different than that of other chemicals that are not biodegradable (i.e., are recalcitrant) in similar settings. Specifically, the vapor concentrations of aerobically biodegradable chemicals exhibit greater attenuation than those of recalcitrant chemicals when the subsurface availability of oxygen is adequate.

Given the foregoing conceptual model of vapor intrusion and summary of modeled scenarios (EPA 2012b), the degree to which vapor intrusion is a pathway of concern can vary widely from site to site and from building to building within a site. Field observations and measurements demonstrate this—that is, indoor air concentrations and soil gas concentrations can exhibit significant temporal variations even for a single building (EPA 2012a) and suggest that the mass flux of vapors via soil gas entry may be highly variable, perhaps even episodic rather than continuous, due to varying driving forces and sub-slab soil gas concentrations.

2.5 Consideration of Indoor and Outdoor Sources of VOCs

Indoor air in many buildings will contain detectable levels of a number of vapor-forming chemicals whether or not the building overlies a subsurface source of vapors (EPA 2011a), because indoor air can be impacted by a variety of indoor and outdoor sources. Indoor sources of volatile contaminants include the use and storage of consumer products (e.g., cleaners, air fresheners, aerosols, mothballs, scented candles, and insect repellants), combustion processes (e.g., smoking, cooking, and home heating), occupant activities (e.g., craft hobbies, home improvements, automotive repairs), and releases from interior building materials (e.g., carpets, insulation, paint, and wood-finishing products). Outdoor sources of volatile chemicals may arise due to releases from nearby sources such as industrial facilities, vehicles, yard maintenance equipment, fuel storage tanks, and paint or pesticide applications; regional sources such as air emissions from regional industry, vehicle exhaust, agricultural activities, and fires; or global sources, such as distant air emissions. The outdoor air surrounding a building is referred to as "ambient air" throughout the Final VI Guidance. The contribution of indoor and outdoor sources of vapors (or both) to indoor air concentrations is referred to as "background" throughout this guidance.

To determine if subsurface sources are responsible for indoor air contamination, EPA recommends that such background sources of air contaminants be identified and distinguished from volatile contaminants arising from vapor intrusion. Section 6.3.5 of the Final VI Guidance describes and recommends approaches for this purpose.

3.0 OVERVIEW OF VAPOR INTRUSION GUIDE

This section provides an overview of this guidance document and the general framework of the vapor intrusion assessment and mitigation process, which is illustrated in Figure 3-1. This section opens with a description of subsurface contaminants that have the greatest potential to pose a health concern via vapor intrusion, based upon their volatility and toxicity.

3.1 Contaminants of Potential Concern

Several physicochemical criteria may be considered for defining volatility[26] and identifying when toxic chemicals are present at levels of potential health concern. For purposes of this guidance, a chemical generally is considered to be "vapor-forming" if:

1) its molecular weight is less than 200 grams per mole (g/mol) (EPA 1991b, Section 3.1.1), vapor pressure is greater than 1 milliliter of mercury (mm Hg), or Henry's law constant (ratio of a chemical's vapor pressure in air to its solubility in water) is greater than 10^{-5} atmosphere-meter cubed per mole (atm m^3 mol^{-1}) (EPA 1991b, Section 3.1.1; EPA 2002c, Appendix D); and

2) the vapor concentration of the pure component exceeds the indoor air target risk level if the vapor source is in soil, or, if in groundwater, the saturated vapor concentration exceeds the target indoor air risk level.

Appendix A identifies chemicals that meet these criteria. EPA recommends that these chemicals be routinely evaluated during vapor intrusion assessments conducted in accordance with the Final VI Guidance, when they are present as subsurface contaminants.[27]

3.2 Vapor Intrusion Assessment

The approach for assessing vapor intrusion will vary from site to site, because each site will differ in its circumstances. For example, the information available for evaluating vapor intrusion potential will vary depending upon when vapor intrusion is first considered during a site's investigation-and-cleanup life cycle. Many sites can be evaluated for potential vapor intrusion during the normal course of an initial site assessment. Examples include brownfield sites that are intended for redevelopment and buildings where chemical odors have been reported. The data available for evaluating vapor intrusion may be very limited at the outset for these situations. At the other end of the investigation and cleanup life cycle, certain sites with long-

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[26] In chemistry and physics, volatility refers to the tendency of a substance to form vapors, which are molecules in a gaseous state, and escape from a liquid or solid. Volatility is directly related to a substance's vapor pressure and Henry's law constant. Volatility is indirectly related to a substance's molecular weight (i.e., substances with lower molecular weights tend to volatilize more readily than substances with similar molecular structures that have higher molecular weights).

[27] The list of vapor-forming substances warranting consideration for potential vapor intrusion may be modified in the future as toxicity values are updated.

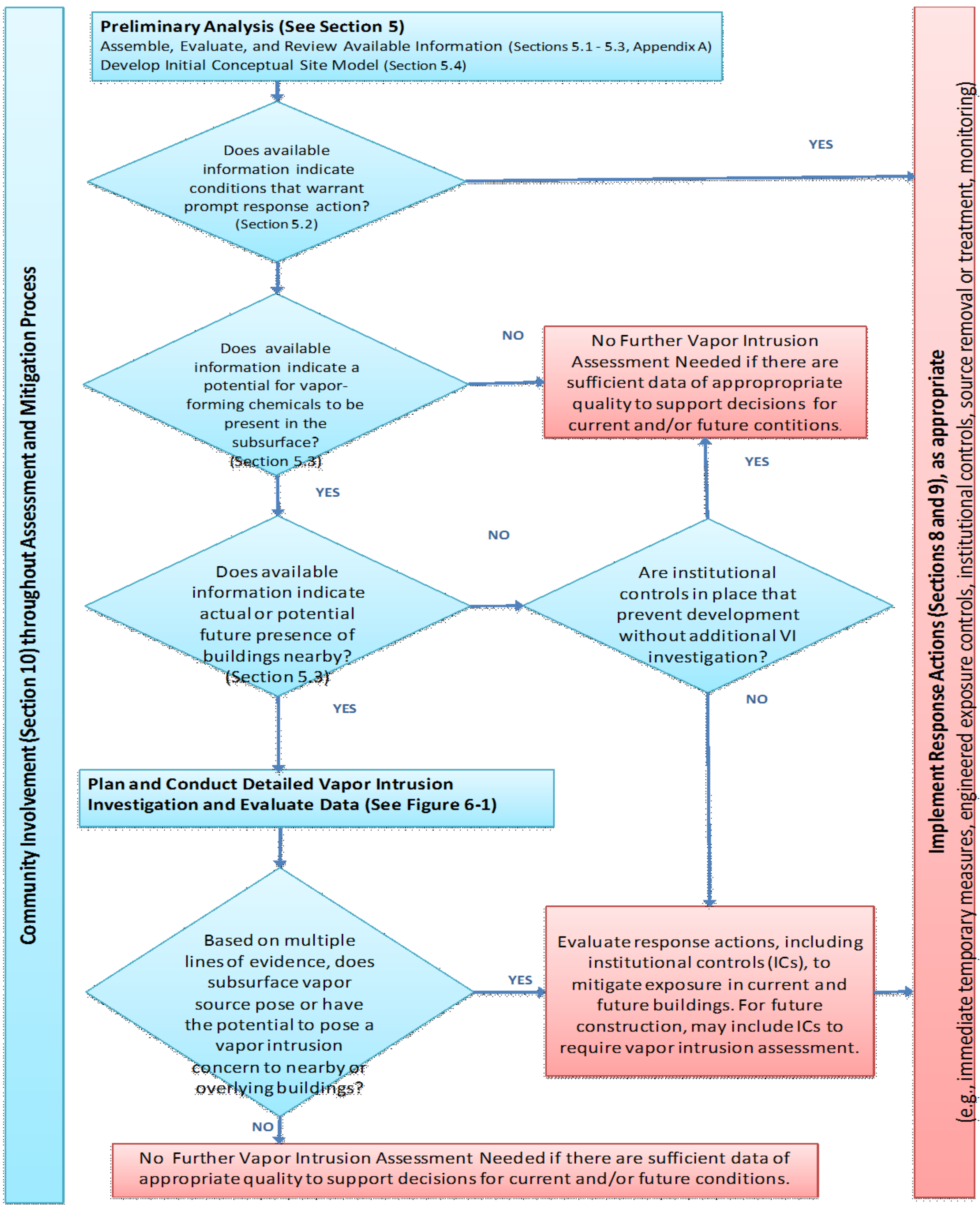

Figure 3-1 Overview of Vapor Intrusion Assessment and Mitigation

term cleanups underway for contaminated groundwater may be evaluated for vapor intrusion during periodic reviews of remedy performance and groundwater monitoring data.[28] In such situations, detailed information about the nature and extent of subsurface contamination and the relevant hydrogeologic conditions may already exist. In addition, there are different scenarios for vapor intrusion (EPA 2012b), depending on characteristics of the source (e.g., types, chemicals of concern, mass, distribution, and distance from building(s)), subsurface conditions and migration pathways (e.g., soil types and layering, existence of preferential pathways due to geology or infrastructure, and existence of any impediments to vapor migration), building susceptibility (e.g., age, design, construction, condition), lifestyle factors (e.g., keeping windows open or closed), and regional climate. For these reasons, every site (and every building) will not warrant the same approach to or intensity of assessment for vapor intrusion.

Broadly speaking, two general levels of vapor intrusion assessments can be distinguished:

1) A <u>preliminary analysis</u> utilizes available and readily ascertainable information to develop an *initial* understanding of the potential indoor air exposure and risk posed by vapor intrusion, which would typically be performed as part of an initial site assessment. The recommended information, approaches, and practices for conducting a preliminary analysis are described in Section 5.0.

2) A <u>detailed investigation</u> is generally recommended when the preliminary analysis indicates that subsurface contamination with vapor-forming chemicals may be present underlying or near buildings. It is typically performed as part of the site investigation stage. The recommended approaches and practices for conducting detailed vapor intrusion investigations are described in Section 6.0.

Considerable information, primarily empirical, has been generated regarding evaluation of the vapor intrusion pathway since the pathway emerged as a national issue in the late 1990s and especially in the past ten years. Broadly speaking, this information demonstrates that the vapor intrusion pathway can be complex. (The conceptual model of vapor intrusion provided in Section 2.0 identifies many of the potential complicating factors.) As a result, current practice suggests that the vapor intrusion pathway generally be assessed using multiple lines of evidence.

Therefore, EPA recommends that site assessors generally collect and evaluate multiple lines of evidence, including qualitative information, to support decision-making regarding the vapor intrusion pathway. Lines of evidence to evaluate the vapor intrusion pathway were identified in Section 2.0 and are discussed further in Sections 5.0 through 7.0.

3.3 Building Mitigation and Subsurface Remediation

The NCP expresses the preference for response actions that eliminate or substantially reduce the level of contamination in the source medium to acceptable levels, thereby achieving a permanent remedy. In the case of vapor intrusion, such a response action would entail

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[28] These situations can arise, for example, if the groundwater remedy was selected in the 1980s (long before vapor intrusion became recognized as a potentially significant exposure pathway), or if supplemental groundwater data indicate that the plume is migrating toward new inhabited areas.

eliminating or substantially reducing the level of vapor-forming chemicals in groundwater and subsurface soil via remediation. Section 8 discusses source remediation and associated institutional controls (ICs) and monitoring for vapor intrusion mitigation, including criteria for their termination.

Because comprehensive remediation[29] of the subsurface environment often entails prolonged periods to attain cleanup levels, problems of unacceptable vapor intrusion are often promptly addressed, at least on an interim (early action) basis, by engineered exposure controls for mitigating vapor intrusion into buildings. Engineered exposure controls[30] can generally be deployed and generally become effective quickly. Interim building mitigation methods are authorized by the NCP (Section 9.0), as necessary and appropriate, to promptly reduce threats to human health. Section 8 also summarizes technical information about specific exposure controls and provides guidance about their operation, maintenance and monitoring and associated ICs, including criteria for their termination.

Functionally, engineered exposure controls can be categorized into two basic strategies:

- Those that seek to prevent or reduce vapor entry into a building. These methods are more commonly implemented when needed. [31]

- Those that seek to reduce or eliminate vapors that have entered into a building,

In accordance with the foregoing conceptual model of vapor intrusion (Section 2.0), entry of the vapors into a building may be prevented or reduced by any of several techniques, which have the following objectives:

- Remove or reverse the driving forces (e.g., mitigate building under-pressurization) for vapor intrusion into the building.

- Eliminate or minimize identified vapor entry routes into the building (e.g., caulking, grouting, or otherwise sealing all holes, cracks, sumps and other foundational openings or creating a barrier between the soil and the building that blocks entry routes from the soil gas into the building).

Engineered exposure controls that entail mechanical systems and forces are often referred to as "active." Engineered exposure controls that do not involve mechanical operations are often

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[29] For purposes of this document, "remediation" is intended to apply to interim and final cleanups, whether conducted pursuant to RCRA corrective action, the CERCLA removal or remedial programs, or using EPA brownfield grant funds with oversight by state and tribal response programs. In addition to permanent remedies for subsurface vapor sources, site remediation may also entail implementation of ICs and construction and operation of engineered systems to reduce risks to human health and the environment posed by environmental pathways other than vapor intrusion.

[30] Even when operated for prolonged periods, mitigation systems can be considered 'interim' remedies for purposes of this guidance, because their implementation does not substitute for remediation of the subsurface source(s) of vapor-forming contamination.

[31] Mitigation methods that prevent or reduce vapor entry into a building from subsurface sources would generally also be expected to reduce radon entry.

referred to as "passive." Many building mitigation systems rely on both active and passive strategies.

Engineered exposure controls that seek to reduce or eliminate vapors that have entered into a building can also be effective. In some instances, they can be implemented more readily than engineered exposure controls that reduce or eliminate entry of the vapors into a building. Typically, the simplest approach to limiting the concentration levels in occupied indoor spaces is to increase building ventilation (i.e., increase the rate at which indoor air is replaced with outdoor air).[32] Alternatively, vapor-forming chemicals are removed from indoor air using an adsorbing material (such as activated carbon) that can be either properly disposed of or recycled. Building mitigation methods that act upon vapor-forming chemicals in indoor air (i.e., rely upon enhanced ventilation or treatment) are generally capable of reducing background levels of chemicals, in addition to reducing indoor levels of vapor-forming chemicals that intrude from subsurface sources.

3.4 Preemptive Mitigation ("Early Action")

There may be situations where a party may wish to implement mitigation or control measures for vapor intrusion, even though only limited lines of evidence or measurements may be available to characterize the overall vapor intrusion pathway. For example, a party may be aware that vapor intrusion has been documented at neighboring structures, where measures are being implemented to mitigate the vapor intrusion pathway. A party may conclude there is a reasonable basis to take action, but each building presents a fact-specific situation that calls for its own individual judgement. Likewise, it may be appropriate and cost-effective to design, install, operate, and monitor engineered exposure controls for individual buildings to mitigate vapor intrusion in newly constructed buildings, or in buildings to be constructed in the future, that are located in areas of vapor-forming subsurface contamination, rather than potentially allow vapor intrusion to occur later and assess vapor intrusion after the fact.

The term "preemptive mitigation/early action" is used in this guidance to describe these situations.[33] The decision for preemptive mitigation/early action arises from precaution and from recognizing that:

- Installing engineered exposure controls in buildings is typically a cost-effective means of protecting human health and normally can be implemented relatively quickly in many buildings while subsurface contamination is being delineated or remediated.

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[32] Exhausting air from the building will generally contribute to building under-pressurization, which may result in increased intrusion of soil gas into the building, which may offset the advantages of ventilation. On the other hand, introducing outdoor air at a rate slightly greater than the exhaust rate can create over-pressurization, which opposes the primary driving force for vapor intrusion. In these ways, ventilation may also affect the driving forces for vapor intrusion. In addition, it can be difficult to establish a ventilation rate that mitigates vapor intrusion and yields an environment conducive to human occupancy (e.g., considering air temperature or moisture).

[33] The term 'preemptive' has been used to describe the use of various types of controls that can prevent vapor intrusion from occurring prior to having fully demonstrated that unacceptable vapor intrusion currently exists in specific buildings being considered (EPA 2010).

- Conventional vapor intrusion investigations can be disruptive for building occupants (residents, workers, etc.) and owners.

- Comprehensive subsurface characterization and investigation of vapor intrusion can entail prolonged study periods, during which time building occupants and owners and others may have questions and concerns about potential risks from indoor air exposures to subsurface vapors.

Early action and interim action are allowed by federal environmental protection statutes, regulations, and guidance, including CERCLA, as amended, and RCRA, as amended – see Section 9.2 of the Final VI Guidance. Other aspects of preemptive mitigation/early action are also discussed in Section 9.0, including situations and criteria for decision-makers to consider.

3.5 Community Outreach and Involvement

OSWER is committed to enhancing transparency and improving upfront collaboration with community stakeholders regarding land cleanup, emergency preparedness and response, and management of hazardous chemicals and wastes. OSWER's Community Engagement Initiative (CEI), in particular, is designed to enhance OSWER's and the Regional offices' engagement with local communities and stakeholders (e.g., state and local governments, tribes, academia, private industry, other federal agencies, and nonprofit organizations) to help them participate meaningfully in government decisions regarding OSWER's nationwide programs.

Proper and sustained community outreach and engagement efforts are critical to the effective implementation of work plans for site-specific vapor intrusion assessment and mitigation. Because assessing the vapor intrusion pathway may involve sampling in a home or workplace, as well as other temporary inconveniences (e.g., assisting in reducing indoor sources of contaminants), individual, one-on-one communication with each property owner or renter generally should be considered. Building-by-building contact and communication are recommended as the most effective means of educating the community and obtaining access needed to assess, mitigate, and monitor the vapor intrusion pathway. Personal contact is further recommended to establish a good working relationship with each home or building owner or renter and to build trust. In many instances, local churches, ethnic organizations, and other community groups can be sought for assistance in reaching out to affected community members.

Vapor intrusion education and training are important components of proper and sustained community outreach and engagement efforts. Informing affected citizens about the vapor intrusion pathway and the cleanup process can contribute to building trust and can lay a better foundation for fostering meaningful community participation in the overall assessment and risk management process.

Recognizing the importance of proper community outreach and engagement efforts, EPA staff are highly encouraged to consult with colleagues experienced in community outreach and utilize available EPA planning resources, including those discussed in Section 10.0, which provides OSWER's community involvement planning guide for vapor intrusion projects. Like EPA, the ITRC also recommends implementing a community outreach program that provides timely information to concerned citizens and property owners.

4.0 CONSIDERATIONS FOR NONRESIDENTIAL BUILDINGS

This section summarizes EPA's general recommendations to consider in making decisions about evaluating and addressing potential vapor intrusion for nonresidential buildings pursuant to CERCLA and RCRA, including decisions that a response action or corrective action is not currently warranted. As used in this guidance, the phrase "nonresidential buildings" may include, but is not limited to, institutional buildings (e.g., schools, libraries, and hospitals), commercial buildings (e.g., hotels, office buildings, and retail establishments); and industrial buildings where vapor-forming substances may or may not be routinely used or stored.

When evaluating nonresidential buildings at sites that have subsurface contamination with vapor-forming chemicals, EPA generally recommends that building owners or lessees be contacted for information about building occupants potentially exposed to subsurface vapor intrusion, as well as any training, equipment, or engineering controls to mitigate inhalation exposures. Building occupants include workers, as well as expected visitors, customers, and suppliers. EPA generally should take all appropriate actions to protect human health and the environment from subsurface sources of chemical exposure in accordance with federal statutes,[34,35] regulations, and OSWER guidance,[36] taking into account the workplace setting. These actions may include sampling indoor air to assess exposure levels of building occupants to subsurface contaminants and implementing interim mitigation measures to control, reduce, or eliminate exposure indoors to vapors emanating from subsurface sources.

The approach for investigating vapor intrusion will vary from site to site, and from building to building, due to site- and building-specific factors and circumstances, including the nature, locations, and extent of subsurface contamination and the size, structural conditions and uses of buildings, and background levels in the workplace. Generally, EPA should consider the following factors when making decisions pertaining to vapor intrusion at nonresidential buildings, including decisions as to whether indoor air sampling, soil gas sampling underneath the building, or interim measures to mitigate vapor intrusion and reduce associated indoor air exposures for a nonresidential building may be warranted:

1) The characteristics of the populations potentially exposed to vapor-forming chemicals in the indoor air of the nonresidential building, including, for example, whether:

   a) Members of the general public are or may be present under current conditions.

   b) Sensitive populations (e.g., children) are or may be present under current conditions.

   c) Minority, low-income, or indigenous populations are or may be present under current conditions who may experience disproportionate impacts.

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[34] Protection of human health and the environment is required by CERCLA and RCRA and is addressed in the NCP, as summarized in Section 1.2.

[35] See, for example, CERCLA Section 101(22).

[36] See, for example, OSWER Directive 9355.0-30 (*Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*) (EPA 1991a).

2) The potential for vapor intrusion and any existing or planned engineering or institutional controls in the building. Questions to consider include, for example:

   a) Can subsurface vapor intrusion be identified as a potential cause of unacceptable human health risk to building occupants?

   b) Can subsurface remediation (e.g., excavation of contaminated soil or soil vapor extraction beneath the subject building) that is planned or underway reduce risk to human health from vapor intrusion within a time frame that is protective for any potential current or near-term exposures in the building?

   c) Are airborne toxic chemicals independent of any vapor intrusion (e.g., indoor use and storage of chemicals) present in the nonresidential building? Are the chemicals the same as the vapor-forming toxic substances in the subsurface? How does the risk from indoor exposure to these indoor-sourced chemicals and concentrations compare to known or potential risk arising from vapor intrusion?

   d) Do work practices and engineering controls currently in place ensure protection of all building occupants who may be exposed via the vapor intrusion pathway?

   e) Are enforceable ICs or other control mechanisms in place to ensure that current land use and workplace practices remain protective regarding indoor air exposures from vapor intrusion to all building occupants? Have these ICs and control mechanisms been communicated and documented to EPA? Can they be readily monitored and enforced?

EPA recommends documenting any decision not to undertake investigation or mitigation for vapor intrusion in a nonresidential building. EPA may consider reviewing these decisions, as appropriate, if the land use changes or new information becomes available that suggests circumstances supporting past risk management decisions have changed and prompt the need to revisit those decisions.[37] It is recommended that EPA request from property owners and building tenants timely notification of significant changes in building ownership, uses, access by the general public, or building construction (e.g., renovations), which may affect its risk management decisions pertaining to potential vapor intrusion assessment and mitigation, subsurface remediation, or ICs.

Regardless of decisions about indoor air sampling, soil gas sampling underneath the building, or interim measures to mitigate vapor intrusion, EPA may proceed with activities such as the following:

- Subsurface investigation to delineate the areal extent of a subsurface vapor plume in accordance with applicable statutes, regulations and OSWER guidance.

[37] OSWER Directive 9200.2-84 (EPA 2012d) provides a recommended framework for considering vapor intrusion while evaluating remedy protectiveness in the context of the Superfund five-year review process.

- Subsurface remediation to reduce or eliminate subsurface sources of vapors in accordance with applicable statutes, regulations and OSWER guidance in order to protect human health and the environment.

5.0 PRELIMINARY ANALYSIS OF VAPOR INTRUSION

A site may be identified based on reports to the National Response Center, citizen complaints or inquiries, state agency referrals, or other information (e.g., site history, land use, site inspections) obtained by EPA. This section describes EPA's recommended approach for conducting preliminary analyses for vapor intrusion using pre-existing and readily ascertainable information to develop an initial understanding of the vapor intrusion potential at a site.

Depending upon the nature and reliability of the available information, it may be possible to determine whether a vapor intrusion investigation or a response action is warranted. If the available information is not reliable or adequate for these purposes, however, additional data collection generally is recommended.

This section:

- Explains the recommended types of information that generally should be obtained when a site is first considered for vapor intrusion (see Sections 5.1, 5.3, 5.4, and 5.5).
- Identifies some of the site conditions for which prompt action is generally warranted (see Section 5.2).
- Illustrates some of the site conditions for which further evaluation of the vapor intrusion pathway might be warranted (see Sections 5.3, 5.4, and 5.5).
- Describes the recommended approaches to evaluating the reliability of pre-existing information, including any sampling data (see Sections 5.1 and 5.5).

5.1 Assemble, Evaluate, and Review Available Information

The recommended first step in a preliminary analysis generally entails assembling and reviewing relevant information that is available at the time for the site. At a minimum, information about potential subsurface sources of vapors and the presence of nearby buildings should be developed and evaluated. For some sites, such as sites being evaluated for redevelopment (EPA 2008a), information about contiguous or nearby facilities also may be relevant, because vapors can encroach from nearby facilities due to migration of contaminated groundwater or soil gas, even though vapor-forming chemicals may not have been used at the site.

The following recommended types of information are often available through documents (e.g., federal, state, tribal and local government records) or through interviews with individuals knowledgeable about the facility or site (e.g., past and present owners, operators and occupants; area residents or workers):

- History and descriptions of the types of operations and activities that occurred on or near the site.
- Information or records about the types of chemicals that may have been used or disposed of at the site.

- Information such as the occurrence of odors, reports of dumping liquids at the site, observations of unreported waste disposal practices, or other indications of chemical presence and release.
- Adverse physiological effects reported by building occupants (e.g., dizziness, nausea, vomiting, confusion).
- Evidence of subsurface intrusion of groundwater (e.g., wet basements) reported by building owners or occupants.

Such information usually can be reviewed and weighed together to assess whether vapor-forming chemicals (see Section 3.1) were used, stored, or handled at or near the site and were or may have been released to the subsurface environment. In general, anecdotal information obtained in interviews should be used cautiously.

In addition, the following types of information may be available through documents, interviews with individuals knowledgeable about the facility or site, or reconnaissance and site inspection:

- Locations, ownership, occupancy, and intended use of buildings on or near the site.
- Current and reasonably anticipated future land use on and near the site.
- Location of subsurface utility corridors.

Evaluation of such information usually can help determine whether human populations are present currently or are reasonably expected to be present in the future, who may become exposed to any intrusion of vapors from the subsurface into a building(s). Zoning, land use planning, and related information may also need to be consulted to identify reasonably anticipated future land use and building types in areas where buildings do not exist or to ascertain whether reasonably anticipated uses of existing buildings are likely to change.

The available data should be evaluated to identify any data gaps for purposes of the preliminary analysis. For example, has the history of operations and primary activities been established for the site and all contiguous properties, including currently vacant land? To the extent that there are significant data gaps, EPA recommends that additional data gathering (e.g., interviews, records review) generally be planned and conducted.

The available data also should be evaluated to assess its reliability and internal consistency. For example, if the available information about operations and activities at a specific property comes only from area residents, EPA recommends additional efforts to identify, contact, and interview current and past owners to obtain this information. For example, if anecdotal information about current activities at a specific property is in conflict with common knowledge about local zoning, EPA recommends that additional data gathering and evaluation be identified, planned, and conducted to resolve the inconsistency.

Section 5.5.1 describes additional considerations for evaluating the reliability of sampling data that may be available for some sites at the preliminary analysis stage.

5.2 Identify and Respond to Any Condition that Warrants Prompt Action

The following conditions generally indicate a need for prompt action:

- Explosive conditions posing safety concerns that warrant urgent intervention are reasonably suspected to exist when measured concentrations of vapors in the building, utility conduits, sumps, or other subsurface drains directly connected to the building exceed one-tenth (10%) of the lower explosive limit (LEL).[38] EPA recommends evacuation of buildings with potential explosion and fire hazards, along with notification of the local fire department about the threat.

- Conditions posing health concerns that warrant urgent intervention are reasonably suspected to exist when estimated exposure concentrations of vapors in the building exceed health-protective concentrations for short-term or acute exposure, as described in Section 7.5.2. Ventilation, indoor air treatment, or evacuation may be implemented to mitigate these conditions promptly (see Section 8.2.1).

The following conditions may indicate a need for prompt action:

- Odors reported by occupants, particularly if described as “chemical,” “solvent,” or “gasoline.” The presence of odors does not necessarily correspond to adverse health or safety impacts, and the odors could be the exclusive result of indoor vapor sources; however, it is generally prudent to investigate any reports of odors as the odor threshold for some chemicals exceeds their respective LEL or health-protective concentrations for short-term or acute exposure.

- Physiological effects reported by occupants (e.g., dizziness, nausea, vomiting, confusion, etc.). These effects may or may not be due to subsurface vapor intrusion (or even other sources of indoor vapors); however, it is generally prudent to investigate any such reports.

- Wet basements in areas where groundwater is known to contain vapor-forming chemicals (Appendix A) and the water table is shallow enough that the basements are prone to groundwater intrusion or flooding. This condition is particularly important where there is evidence of light NAPL (LNAPL) on the water table directly below the building or direct evidence of intrusion of liquid-phase contamination (i.e., liquid chemical or dissolved in water) inside the building.

EPA generally recommends testing of indoor air (see Sections 6.4.1 and 6.3.4) as soon as practical in buildings where chemical odors, physiologic effects, or intruding contaminated groundwater are reported. When the results of such testing reveal hazardous conditions

[38] The Occupational Safety and Health Administration of the U.S. Department of Labor (OSHA) considers concentrations in excess of one-tenth of the LEL to be a hazardous atmosphere in confined spaces [29 CFR 1910.146(b)]. The National Institute for Occupational Safety and Health (NIOSH) has designated such concentrations as immediately dangerous to life or health (IDLH).The Vapor Intrusion Screening Level Calculator (EPA 2012c) provides LELs for vapor-forming chemicals to facilitate identification of potential explosion hazards, as discussed further in Section 7.5.1.

warranting prompt response action, then ventilation, indoor air treatment, or evacuation may be implemented to mitigate these conditions promptly (See Section 8.2.1).

Preemptive mitigation/early action (see Section 9.0) may still warrant consideration after urgent safety or urgent health concerns have been addressed. Expected work conditions and anticipated hazards should be described and addressed in health and safety planning for all building- or site-specific actions.

5.3 Determine Presence of Buildings and Vapor-forming Chemicals

Two conditions, at a minimum, must be present for the vapor intrusion pathway to pose a potential human health threat:

1) There must be a source of vapor-forming chemicals in the subsurface environment (i.e., in groundwater or soil, or a primary vapor release such as from natural gas transmission lines). Appendix A lists chemicals that typically have the potential to pose an unacceptable health risk through the vapor intrusion pathway. Those chemicals likely to be present as subsurface contaminants should generally be evaluated during vapor intrusion assessments conducted in accordance with this Final VI Guidance in areas where buildings are present or future buildings could be constructed above or near the subsurface vapor source(s). In the absence of environmental sampling data, the potential presence of vapor-forming chemicals in the subsurface may be inferred from site information, as identified in Section 5.1 (e.g., site history).

2) Buildings are present or could be constructed in the future above or "near" the subsurface vapor source(s). For purposes of this guidance and its recommendations for evaluating potential health risks posed by toxic vapors, "building" refers to a structure that is regularly occupied and used by humans (or could be occupied and used in the future). This would include, for instance, homes, offices, stores, commercial and industrial buildings, etc., but would not normally include open sheds, carports, pump houses, or other structures that are not regularly occupied by humans. For purposes of evaluating potential explosion hazards, however, the term "building" generally includes occupied and non-occupied structures. Existing buildings can be identified during inspections of the land areas overlying and near subsurface vapor sources. The potential presence of buildings in the future may be inferred from site information, as identified in Section 5.1. Buildings within 100 feet laterally of subsurface vapor sources (or 100 feet vertically of underlying vapor sources) should be considered "near" (see Section 6.2.1) for purposes of a preliminary analysis, under the assumption that preferential vapor migration pathways are absent.[39]

[39] Preferential migration pathways are defined and discussed in Section 5.4. When present, they may facilitate subsurface vapor migration over distances greater than 100 feet.

If the available information is deemed reliable, well documented, and sufficient (see Section 5.1) and indicates that neither of these conditions is met, then it may not be appropriate to conduct further vapor intrusion assessments.[40]

> *Example: From 1920 to 1931, the ABC Mining Company obtained and shipped iron ore from a local deposit. Ore from the mine was shipped by rail to a different location where it was milled and processed to extract the metal. Although no company records are available for the mine, a review of mining techniques indicates that solvents and other vapor-forming chemicals were not used in the mining process during the 1920s and 1930s. Former mining structures have been removed, and the site is currently vacant. The city has proposed redeveloping the site with bike and hiking trails but no buildings or other structures for storage or site maintenance support. Based on the information and findings, the need for further assessment of the vapor intrusion pathway due to mining-related contamination is not indicated.*

If, on the other hand, there is evidence to demonstrate that a release of vapor-forming chemicals to the subsurface has occurred (e.g., environmental sampling data indicate detectable levels of a vapor-forming chemical(s) in potential source media)[41] or may have occurred underneath or near a property with buildings, then further vapor intrusion assessment is generally warranted, including development of a conceptual site model (see Section 5.4) and investigation of site-specific conditions (see Section 6.0).

> *Example: The XYZ Recycling Center site was used from 1963 to 1984 for the collection and recycling of industrial solvents and other fluids. The site was repeatedly cited by the State and City for improper handling and disposal of solvents, and was closed in 1985. Groundwater data indicate the presence of multiple CHCs. Buildings overlying the contaminated groundwater are currently used mainly for storage of non-chemical goods, but the site has been proposed for future residential or commercial redevelopment. Based on the foregoing information and findings, further assessment of the potential for vapor intrusion is warranted, including risk-based screening of the groundwater data (see Section 6.5).*

If a release of vapor-forming chemicals to the subsurface is known or suspected to have occurred at or near the site, but buildings are not present and none are reasonably anticipated in the future (e.g., the contaminated source underlies an open space, recreational area, or wildlife refuge), then further vapor intrusion assessments may not be appropriate. It may be appropriate, however, to establish an IC requiring a vapor intrusion investigation or building mitigation[42] in the future, in case land use were to change. ICs for building mitigation and

[40] In accordance with federal environmental protection statutes, regulations, and OSWER guidance, a subsurface investigation may still be warranted for non-volatile substances and for other potential exposure pathways such as those identified in Section 1.3.

[41] Section 6.5 provides information on how such data may be used in a quantitative fashion to screen the site further.

[42] If, for example, a developer is considering acquiring and building on land that contains subsurface contamination with vapor-forming chemicals, the developer could retrofit existing buildings or build new buildings with vapor mitigation systems without first conducting an extensive vapor intrusion investigation (see Section 9.0). As summarized in Section 3.3, building mitigation systems for the vapor intrusion pathway may eliminate or minimize vapor entry routes and/or remove or reverse the driving forces for soil gas entry (i.e., may be passive and/or active).

subsurface vapor source remediation are discussed further in Section 8.6 of this guidance document. In addition, a subsurface investigation may be warranted at some point to characterize subsurface contamination and assess the need for subsurface remediation to protect the environment and human health for potential exposure pathways other than vapor intrusion. For example, site investigations to characterize the nature and extent of groundwater contamination and support assessments of risk to human health through the ingestion pathway are typically conducted in accordance with federal statutes and regulations (e.g., CERCLA and RCRA).

5.4 Develop Initial Conceptual Site Model

EPA recommends that the planning and data review team develop an initial conceptual site model (CSM) for vapor intrusion and conduct a site investigation for vapor intrusion (see Section 6) when the preliminary analysis indicates the presence of subsurface contamination with vapor-forming chemicals underlying or near buildings. The initial CSM (and any subsequent refined CSM) can be used to support evaluations of the adequacy of the available information, to guide any vapor intrusion investigations and to support data selection for risk-based screening (see Section 6.5). The CSM can also provide useful information for supporting prompt development of a strategy for early response actions (see Section 9.0). The remainder of this section discusses recommended information collection that can be useful for developing a CSM. Note that some of the recommended information may not be readily available when a site is first considered for vapor intrusion.

As noted in Section 2.0 and Section 5.3, for the vapor intrusion pathway to be complete, there must be, at a minimum, a source of vapor-forming chemicals in the subsurface and buildings or the potential for future buildings near the subsurface vapor source(s). Therefore, the CSM for vapor intrusion at a minimum should portray the current understanding of the site-specific conditions, including the following:

- Nature (i.e., type, chemical composition), location, and spatial extent of the source(s) of vapor-forming chemicals in the subsurface. For example, it is useful to know which vapor-forming chemical(s) primarily comprise the subsurface vapor source[43] and whether it is also capable of posing explosion hazards.

- Location, use, occupancy, and basic construction (e.g., foundation type) of existing buildings.

The CSM should also portray the current understanding of the hydrologic and geologic setting in and around the subsurface vapor source(s) and the buildings. When these conditions are not well established from existing information, and the preliminary analysis indicates the presence of subsurface contamination with vapor-forming chemicals underlying or near buildings, EPA

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[43] EPA also recommends that the CSM identify any site-specific chemicals of concern that may be biodegradable. When evaluating biodegradable chemical contaminants, the CSM should identify and summarize information and data pertaining to the possible role of biodegradation *in situ* in limiting vapor migration in the vadose zone (see Section 6.3.2) or generating hazardous, volatile products (e.g., methane from anaerobic biodegradation, vinyl chloride as a byproduct of PCE or TCE biodegradation).

recommends that a detailed vapor intrusion investigation be scoped to address these data gaps (see Section 6.3).

Furthermore, the CSM should identify known or suspected preferential pathways that could facilitate vapor migration to greater distances and at higher concentrations than otherwise expected. EPA recommends that buildings with significant preferential pathways be evaluated closely. For the purposes of this guidance, a "significant" preferential pathway is a naturally occurring or anthropogenic (human made) subsurface conduit that is expected to exhibit little resistance to vapor flow in the vadose zone (i.e., exhibits a relatively high gas permeability) or groundwater flow (i.e., exhibits a relatively high hydraulic conductivity) and be of sufficient volume and proximity to a building so that it may be reasonably anticipated to influence vapor intrusion into the building. Significant vertical preferential pathways may result in higher than anticipated concentrations in the overlying near surface soils, whereas significant horizontal preferential pathways may result in elevated concentrations in areas on the periphery of subsurface contamination. Naturally occurring examples include fractures and macropores, which may serve as preferential pathways for either the vertical or horizontal migration of source materials and/or vapors. Anthropogenic examples include utility vaults and conduits, elevator shafts, subsurface drains, and permeable fill that intersect vapor sources or vapor migration pathways. In highly developed residential areas, extensive networks of subsurface utility conduits may be present, which can significantly influence the migration of contaminants.

CSMs for vapor intrusion assessments often need to consider two distinct exposure situations:

1) At some sites and contaminated locations, there are concerns as to whether vapor intrusion may pose a risk to current occupants of the buildings present. For this situation, EPA recommends that building-specific information be available to support the CSM.

2) At other sites and contaminated locations, buildings are not present, but are expected to be constructed, and building-specific information may not be available to support the CSM. For this situation, the CSM may need to consider a hypothetical building constructed anywhere over (or near) the subsurface source of vapor-forming chemicals.

In general, CSMs identify the potentially exposed populations, potential exposure routes, and potential adverse health effects (i.e., toxicity) arising from indoor air exposures. Therefore, the CSM also should identify and consider sensitive populations, including but not limited to:

- Elderly.
- Women of child-bearing age.
- Infants and children.
- People suffering from chronic illness.
- Disadvantaged populations (i.e., an environmental justice situation).

As noted in Section 2.0, the exposure route of general interest for vapor intrusion is inhalation of toxic vapors in indoor air and the human populations of primary interest are individuals living or working in or otherwise occupying a building subject to vapor intrusion. However, EPA recommends that the CSM also identify any site-specific chemicals of concern that have potential for explosion hazards (e.g., methane) or for posing other routes of exposure (e.g., dermal exposure to shallow contaminated groundwater seeping into a basement, which is contaminated).

In documenting current site conditions, EPA recommends that a CSM be supported by maps, cross sections, and site diagrams, and that the narrative description clearly distinguish what aspects are known or determined and what assumptions have been made in its development.

Developing a CSM generally should be the first step in EPA's data quality objective (DQO) process (EPA 2006a). It is rare for a site to have readily available sources of sufficient information to develop a complete CSM when the vapor intrusion potential is first considered. For example, a detailed site-specific investigation may be necessary to characterize the full extent of subsurface vapor sources and geologic conditions underlying nearby buildings (see Sections 6.3.1 and 6.3.2) and to demonstrate the absence of preferential pathways for vapor migration and intrusion. The CSM should be updated as new information is developed and new questions are framed and answered. A well-defined, detailed CSM may also facilitate the identification of additional data needs and development of appropriate detection limits for laboratory and field analyses, which can support planning of the detailed vapor intrusion investigation (see Section 6.2) and site-specific health risk assessment, if any (see Section 7.4). Sections 6.3, 6.4, 7.1, and 7.2 provide additional guidance about data collection and evaluation for purposes of supporting the CSM.

5.5 Evaluating Pre-Existing and Readily Ascertainable Sampling Data

Sites and adjacent facilities that have been the subject of previous environmental investigations or regulatory actions may already have data on contaminant concentrations in site media (i.e., sampling data) when vapor intrusion is first considered. Some of these sites and facilities may be undergoing remediation but warrant a vapor intrusion assessment as a result of changing toxicity information for vapor-forming chemicals, as part of a periodic review of remediation effectiveness and protectiveness, or for other reasons.

If the pre-existing environmental data are deemed reliable and other conditions are met (as described in the remainder of this subsection and in Section 6.5.1), the sampling data may be compared to recommended generic vapor intrusion screening criteria (see Section 6.5) for purposes of developing an initial quantitative perspective about the potential level of exposure and risk posed by vapor intrusion. Such a screening can, for example, help focus a subsequent vapor intrusion investigation (see Section 6.0) or provide support for considering building mitigation as an early action (see Section 9.0). Note that some of the site-specific information generally recommended for supporting a risk-based screening may not be available when a site is first considered for vapor intrusion.

5.5.1 Evaluate Sampling Data Reliability and Quality

To the extent that environmental sampling data are identified for the site or nearby properties, EPA recommends that these data be evaluated to determine whether they are of sufficient quality to support a comparison to recommended generic vapor intrusion screening criteria (see

Section 6.5). Some questions that could be considered when reviewing historical sampling data include:

- How were the samples collected and analyzed? EPA generally recommends using pre-existing data when they have been collected and analyzed by methods considered reliable by today's standards.

- How old are the data? Were analyses conducted for all known or suspected vapor-forming chemicals expected to be present and reasonably expected degradation products? EPA generally recommends using pre-existing data when they can be considered representative of current conditions.

- Were the reporting limits sufficiently low for comparison with vapor intrusion screening criteria? EPA generally recommends using pre-existing data with non-detect results when they can be considered reliable.

- Were multiple locations sampled to assess spatial variability of the results? Were multiple sampling events conducted to assess temporal variability of the results? EPA generally recommends characterizing spatial and temporal variability to increase confidence in data evaluation and decision-making.

EPA also recommends that the reliability of any historical sampling data be assessed by considering the principles for collecting subsurface and indoor air samples that are described in Sections 6.3.1 and 6.4 of the Final VI Guidance. In addition, the EPA's *Guidance for Data Usability in Risk Assessment, Part A* (EPA 1992a) outlines a recommended approach for evaluating whether the data meet the requirements and intended use of the risk assessment. As such, it is a good tool for evaluating the quality and usefulness of historical data collected at a site.

5.5.2 Evaluate Adequacy of the Initial CSM

Before performing any comparison of existing sampling data to recommended generic vapor intrusion screening criteria (see Section 6.5), it is important to verify that site-specific conditions reflect the conditions and assumptions of the generic model underlying the vapor intrusion screening criteria, which are summarized in Section 6.5.1. To verify that the generic vapor intrusion model applies, there is a need for basic knowledge of the subsurface source of vapors (e.g., location, form, and extent of site-specific vapor-forming chemicals) and subsurface conditions (e.g., soil type in the vadose zone, depth to groundwater for groundwater sources), which are important elements of the CSM (see Section 5.4). When these subsurface data are not available, EPA recommends they be collected (i.e., proceed to a detailed vapor intrusion investigation) before conducting risk-based screening of sampling data.

5.5.3 Preliminary Risk-based Screening

If reliable sampling data are available and an adequate CSM has been documented (i.e., sufficient subsurface characterization information exists to adequately characterize the locations, forms, and extent of site-specific vapor-forming chemicals and general subsurface conditions (e.g., hydrologic and geologic setting in and around the source(s) and the buildings)), then a risk-based screening may be useful to obtain some preliminary insights about the potential level of exposure and risk posed by vapor intrusion.

> *Example: A prospective developer of a vacant lot with no history of onsite chemical use is interested in evaluating the potential for vapor intrusion in the future due to potential migration onto the lot of an off-property plume of contaminated groundwater. The extent and nature of the off-property plume have been adequately and recently characterized and geologic conditions near the lot have been characterized, as documented in a publicly available report(s). In this circumstance, it may be possible to support a preliminary screening and obtain some useful insights. For example, if the maximum concentration of each chemical of concern in the off-property plume of contaminated groundwater currently and in the future is less than the generic chemical-specific screening level for groundwater, then vapor intrusion is not expected to be a future concern on the vacant lot, provided there are sufficient data to document that conditions on the vacant lot are in accordance with the generic model behind the vapor intrusion screening levels, as described in Section 6.5.1.*
>
> *Additional data collection, possibly including on-property site characterization, may be warranted to verify that these conditions hold true (i.e., proceed to a detailed vapor intrusion investigation before making final risk management decisions). EPA generally also recommends using post-construction indoor air testing to confirm the screening results based upon the groundwater source data.*

This example reinforces the following general recommendations:

- Site-specific data generally should be collected and evaluated to verify that the subject property reflects the conditions and assumptions of the generic model underlying the VISLs (see Section 6.5.1).
- Multiple lines of evidence (e.g., hydrogeologic information in addition to sampling data) generally should be collected and weighed together in supporting assessments of the vapor intrusion pathway (see Sections 7.1 and 7.2 for further information).
- Multiple rounds of groundwater (or soil gas) sampling results are useful in supporting conclusions that a specific vapor source is stable or shrinking and/or is not expected to pose a vapor intrusion concern (see Sections 6.3.1 and 6.4.5).

Similar recommendations apply in the situation where vapor intrusion potential is being evaluated as part of a periodic review of an existing remedy (prompted, for example, by recent construction of a new building over a contaminated plume that is undergoing remediation) (EPA 2002b, 2012d).

6.0 DETAILED INVESTIGATION OF VAPOR INTRUSION

This section describes EPA's generally recommended approaches and practices for vapor intrusion investigations, which typically entail collecting and evaluating multiple lines of evidence to characterize the vapor intrusion pathway. Section 7 describes EPA's generally recommended approaches and practices for determining, on the basis of the investigation results, whether the vapor intrusion pathway poses a potential health concern to building occupants under current and reasonably expected future conditions and whether response actions are warranted for vapor intrusion mitigation at individual facilities, buildings, or sites.

6.1 Common Vapor Intrusion Scenarios

Vapor intrusion scenarios can be quite varied, owing to the possible combinations of:

- Multiple hazardous chemicals that can form vapors.
- Multiple forms in which these chemicals may be present as contaminants in the subsurface, for example:
  - Residual NAPL and adsorbed-phase chemicals, including LNAPLs that are less dense than water and DNAPLs that are denser than water.
  - Dissolved-phase chemicals in groundwater or soil moisture.
  - Primary vapor releases (e.g., from gas transmission lines).
- The variety of geologic and hydrologic characteristics and conditions in the subsurface environment in which this contamination may occur.
- The variety of buildings (in terms of size, age, condition, and use) and current or expected land use settings (e.g., residential, commercial, industrial, brownfield redevelopment) that may be subject to vapor intrusion from such subsurface contamination.

A few of the possible scenarios are illustrated in Figure 2-1. Many more can be inferred from the conceptual model of vapor intrusion discussed in Section 2.0. Some of the more common scenarios where vapor intrusion has been documented to occur include:

- Groundwater contaminant plumes in shallow aquifers underlying residential and non-residential buildings.
- Soil contamination in the vadose zone underlying commercial or industrial buildings, even when the areal extent of groundwater contamination is limited.

EPA's recommended approaches and practices for vapor intrusion investigations aim to be flexible and adaptable to a wide range of reasonably expected scenarios and are not intended to be prescriptive or exhaustive for any specific scenario.

6.2 Planning and Scoping

Before information or data are collected on Agency-funded or regulated environmental programs and projects, systematic planning is conducted during which performance or acceptance criteria are developed for the collection, evaluation, or use of these data (EPA 2006a).[44] EPA strongly recommends the DQO process as the appropriate systematic planning process for its decision-making and has issued guidance for its application to hazardous waste site investigations pursuant to CERCLA and RCRA (EPA 2000). Appropriately conducted, planning provides greater assurance that the data collected will fulfill specific project needs and that mitigation and subsurface remediation options will be considered early in the process.[45] A clear and logical plan will often facilitate communication with building owners, occupants, and other stakeholders.

Given these considerations, thorough and sustained planning guided by a CSM is usually advisable for detailed vapor intrusion investigations. The initial stages of planning would typically entail gathering readily available existing information and formulating an initial CSM, as described in Section 5.4. The CSM portrays the current understanding of site-specific conditions, including the nature and extent of contamination, contaminant fate and transport routes, potential "receptors" and contaminant exposure pathways. The term "conceptual" merely reflects that the model need not be entirely quantitative and mathematical; it does not denote a simplistic or incomplete understanding of site conditions. The CSM should evolve and be updated as new information is developed and new questions are framed and answered.

Subsequent to formulating an initial CSM based on readily available information, the scope for an initial phase of vapor intrusion investigation would be developed, preferably along with a logical plan for future directions in response to the reasonably expected outcomes of the initial investigatory phases. Initial plans may warrant periodic updates and refinements, particularly when data outcomes are unexpected and prompt the need to reevaluate the CSM. In each case, EPA recommends that the investigation work plan include the identification of and basis for the indoor air screening levels (such as the VISLs) and/or indoor air action levels (i.e., level of each vapor-forming chemical of potential concern that would trigger a response action if exceeded), which would dictate the DQOs for the sampling and analysis methods. In general, the plan should also include a rationale or logic for where and how the data will be collected and over what duration(s), how the data will be interpreted, whether confirmatory sampling will be needed if all sample concentrations are less than the action levels, whether response action(s) would be triggered if sample concentrations exceed the target levels, and similar considerations. Sections 6.3 through 6.6 below provide additional guidance and information for planning and scoping site-specific investigations for vapor intrusion assessment. Figure 6-1 provides a diagram to illustrate such planning and scoping.

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[44] Appendix C provides additional information about EPA's quality system and DQO process.

[45] *Science and Decisions: Advancing Risk Assessment* was prepared by the National Academy of Sciences (NAS) Committee on Improving Risk Analysis Approaches Used by the U.S. EPA (NRC 2009) and is commonly referred to as the "Silver Book." Among other recommendations, the NAS Committee encouraged EPA to focus greater attention on design in the formative stages of risk assessment, specifically on planning and scoping and problem formulation, and to view risk assessments as a method for evaluating the relative merits of various options for managing risk, rather than as an end in itself. In accordance with these recommendations, plausible mitigation and subsurface remediation options (see Section 8) should be considered during development of vapor intrusion investigation plans.

EPA's fundamental approach to evaluating contaminated sites calls for proceeding in a stepwise fashion with early data collection efforts usually limited to developing a basic understanding of the site, as reflected in the CSM.[46] Subsequent data collection efforts focus on filling gaps in the understanding of the CSM and gathering information necessary to evaluate the relative merits of various options for managing risk. Therefore, it is generally recommended to develop and implement a vapor intrusion investigation plan in multiple stages or phases. Such a phased sampling approach encourages the identification of key data needs early in the process to better ensure that data collection provides information relevant to decision-making (e.g., interim action to mitigate vapor intrusion and selection of a cleanup plan for subsurface contamination). In this way, the overall site characterization effort can be scoped to prioritize data collection and minimize the collection of unnecessary data and maximize data quality.

Generally, EPA recommends that the objectives and methods of the investigation be documented in a vapor intrusion work plan. At a minimum, components of the work plan should generally include:

- Narrative description of the rationale and scope of the investigation.
- Summary of the CSM.
- Scaled map(s) illustrating extent of subsurface contamination and readily identifiable landmarks (e.g., streets and buildings).
- Media to be sampled.
- Number, type, and location of and rationale for proposed sampling locations.
- Sampling methods and procedures for each medium.
- Analytic method(s) to be used to obtain chemical concentrations.
- Standard operating procedures of the laboratory and for field instruments.
- Quality assurance project plan (QAPP).

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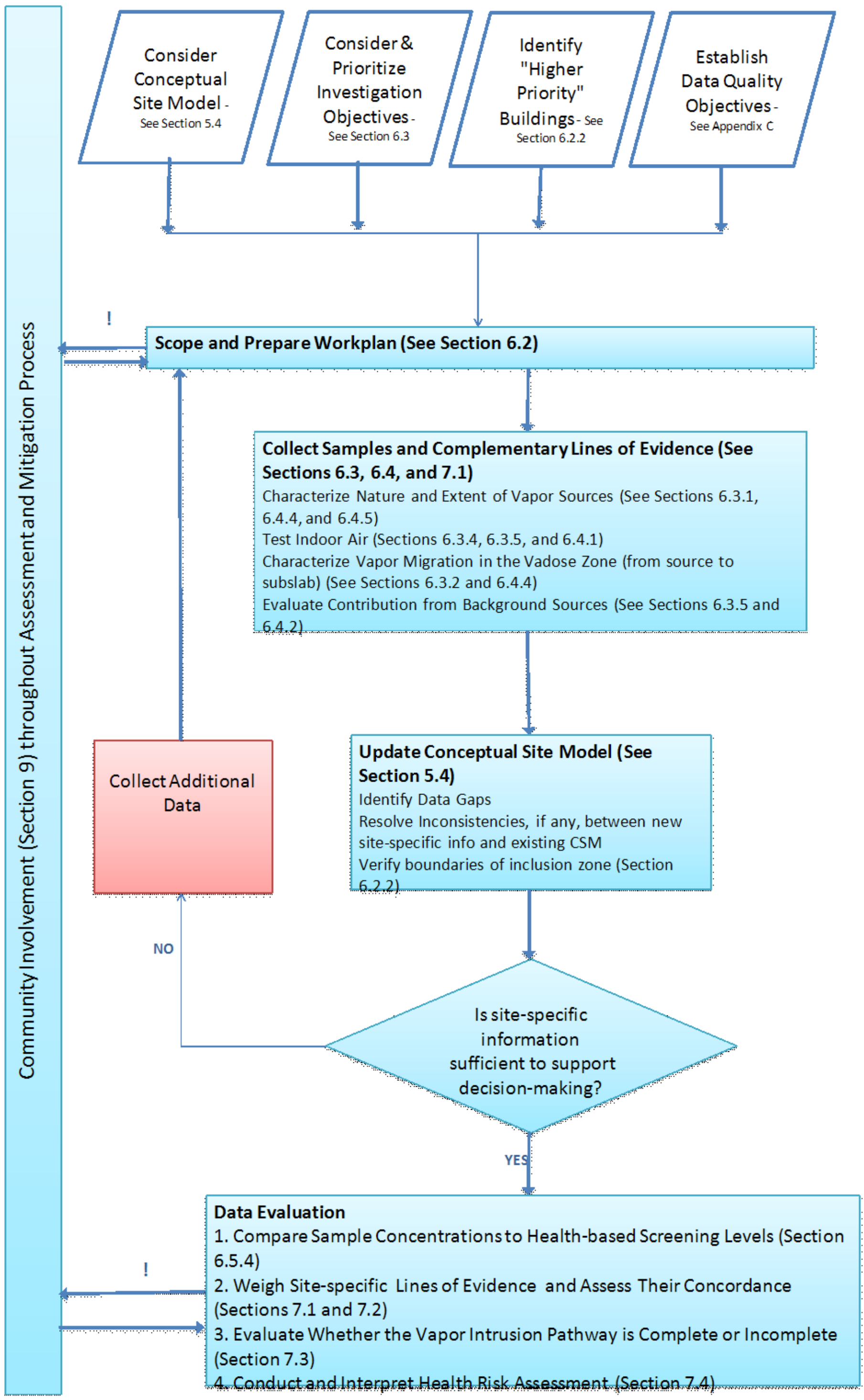
[46] Investigations under CERCLA and RCRA corrective action (CA) explicitly recognize phasing. In these cleanup programs, the first investigatory phase is an *initial site assessment*. The purpose of this activity is to gather information on site conditions (current and historical), releases, potential releases, and exposure pathways. Investigators use this information to determine whether a response action (e.g., removal action or interim cleanup measure) may be needed or to identify areas of concern for further study. Information collected during this phase usually forms the basis for determining whether the next stage, site investigation, is warranted. In the RCRA CA program, the initial site assessment is called the RCRA facility assessment. Under CERCLA, this phase is called the preliminary assessment/site inspection. The purpose of the second phase, site investigation, is to determine the nature and extent of contamination at a site, quantify risks posed to human health and the environment, and gather information to support the selection and implementation of appropriate remedies. In the RCRA CA program, this phase is known as the RCRA facility investigation. Under the CERCLA remedial program, this phase is referred to as the remedial investigation. In addition, the site investigation may itself be conducted in multiple stages (or phases).



Exclamation point (!) indicates important milestone for communication and engagement efforts with affected building occupants and owners.

Figure 6-1 Overview of Planning, Scoping, and Conducting Vapor Intrusion Investigations

- Health and safety plan.[47]

The planning and data review teams for vapor intrusion generally will need to include scientists or engineers with expertise in characterizing subsurface environmental conditions and interpreting and communicating environmental data. In addition, coordination with a human health risk assessor generally will be needed in evaluating the vapor intrusion pathway. Depending upon the complexity of the CSM (see Section 5.4) and data evaluations, these teams also may need to include scientists and engineers with expertise in hydrogeology, inferential statistics, laboratory analysis methods, and building construction, ventilation, and operations and individuals knowledgeable about land use planning, zoning, and land development. In addition, on-site personnel should have appropriate training and experience in hazard identification, workplace practices to foster health and safety, and recommended sampling protocols.

6.2.1 Vapor Intrusion Inclusion Zones

Vapor concentrations generally decrease with increasing distance from a subsurface vapor source, and eventually at some distance the concentrations become negligible. The distance at which soil gas concentrations become negligible is a function of the strength and dimensions of the vapor source, the type of vapor source, the soil types and layering in the vadose zone, the presence of physical barriers (e.g., asphalt covers or ice) at the ground surface, and the presence of preferential migration pathways, among other factors (see, for example, EPA 2012a). Because these factors vary among sites, the distance beyond which structures will not be threatened by vapor intrusion is necessarily a site-specific determination. The extent of the site-specific "inclusion zone" for vapor intrusion should also consider:

- The age of the chemical release and whether sufficient time has elapsed to allow soil gas to migrate from the source to its maximum potential extent.
- Whether the subsurface vapor source is stable or shrinking (i.e., is not migrating or rising in concentration, including hazardous byproducts of any biodegradation).

Recommended Distance for Initial Evaluation. There are limited published empirical data relating observed indoor air concentrations of subsurface contaminants to distance from a source boundary. However, a buffer zone of approximately 100 feet (laterally or vertically from the "boundary" of subsurface source concentrations of potential concern) has generally been used in determining which buildings to include in vapor intrusion investigations when significant surface covers are not present. Specifically, a buffer zone of 100 feet (or approximately two houses wide) has been suggested by several states (Folkes et al. 2007) and is supported, in general, by theoretical analyses that assume the absence of preferential vapor migration pathways and that diffusion is the predominant mechanism of vapor migration in the vadose

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[47] All governmental agencies and private employers are directly responsible for the health and safety of their employees. This general rule applies to many parties involved in the assessment and cleanup of Superfund sites, RCRA corrective action sites, and brownfield redevelopment sites. Standards established pursuant to the Occupational Safety and Health Act are found in Title 29 of the Code of Federal Regulations (29 CFR), which include requirements for training, hazard communication, and site-specific health and safety plans.

zone (Lowell and Eklund 2004). On this basis, buildings within 100 feet laterally of subsurface vapor sources (or 100 feet vertically of underlying vapor sources) generally should be considered "near" for purposes of vapor intrusion investigations, under the assumption that preferential vapor migration pathways are absent.

Anecdotal evidence indicates that in some settings buildings greater than 100 feet from a plume "boundary" may be affected by vapor intrusion, even when diffusion is the presumed mechanism of vapor migration. Moreover, the presence of conduits (e.g., sewers or utility bedding) or preferential hydrogeologic pathways that facilitate unattenuated vapor migration in the vadose zone, and other factors (e.g., presence of extensive surface covers, uncertainties in delineating the boundaries) may extend the vapor migration distance. For these reasons, EPA recommends investigating soil vapor migration distance on a site-specific basis. That is, larger or smaller distances may need to be considered when developing objectives for detailed vapor intrusion investigations and interpreting the resulting data. Data from sub-slab and exterior soil gas sampling (see, for example, Sections 6.4.3, and 6.4.4) and indoor air testing (see, for example, Sections 6.3.4 and 6.4.1) can be collected and evaluated to delineate or confirm areas at specific sites within which buildings are subject to vapor intrusion threats.[48]

Finally, we would note that vapor source types for which use of a 100-foot buffer would typically be inappropriate include:

- Landfills where methane is generated in sufficient quantities to induce advective transport in the vadose zone.
- Commercial or industrial settings where vapor-forming chemicals have been released within an enclosed space and the density of the chemicals' vapor may result in significant advective transport of the vapors downward through cracks or openings in floors and into the vadose zone.
- Leaking vapors from natural gas transmission lines.

In each of these cases, the diffusive transport of vapors may be overridden by advective transport and the vapors may be transported in the vadose zone several hundred feet from the source of contamination.

<u>Criteria for Establishing "Boundaries" of the Plumes that Contain Vapor-forming Chemicals</u>. This guidance is intended to be applied to existing groundwater plumes as they are currently defined (e.g., Maximum Contaminant Levels, state standards, or risk-based concentrations). However, it is important to recognize that some non-potable aquifers may have plumes that have been defined by threshold concentrations significantly higher than drinking-water concentrations. In these cases, contamination that is not technically considered part of the plume may still have the potential to pose unacceptable risks via the vapor intrusion pathway. Consequently, the

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[48] For assessing the extent of soil gas migration from the subsurface vapor source, it is generally necessary to measure soil gas concentrations, either sub-slab soil gas (preferably) or exterior soil gas with a sufficient density to characterize and understand spatial variability. EPA generally recommends comparing soil gas concentrations to the respective VISLs to establish the boundaries of the vapor intrusion inclusion zone.

plume definition may need to be expanded for purposes of defining an inclusion zone for a vapor intrusion investigation. When groundwater is the subsurface vapor source, EPA generally recommends comparing groundwater concentrations to the VISLs to estimate the boundaries of the plume for purposes of establishing the boundaries of the vapor intrusion inclusion zone.

6.2.2 Prioritizing Investigations with Multiple Buildings

At sites where numerous buildings are potentially subject to vapor intrusion (e.g., developed areas with an extensive plume of contaminated groundwater), it may not be feasible or practical to sample indoor air in each building or soil gas underneath or near each building. In the context of a phased investigation, EPA generally recommends a “worst first” approach to investigating buildings. Factors that may warrant consideration in prioritizing buildings for investigation include:

- Source strength and proximity. Buildings overlying and near a source of vapors in the vadose zone would generally be expected to have a greater potential for vapor intrusion than buildings that do not overlie this same vapor source. Where the subsurface vapor source is groundwater, buildings located over higher concentrations or shallower water levels would generally be expected to have a greater potential for vapor intrusion than buildings located over lower concentrations and deeper groundwater plumes.

- Building types and conditions. Buildings that are continuously occupied may pose a more immediate concern than buildings that are not currently occupied, if all other factors (e.g., source strength and proximity) are equivalent. Nonresidential buildings with bay-style doors that are routinely open may be better ventilated than other types of nonresidential buildings, providing greater potential for dilution of vapor-forming chemicals that enter the building via vapor intrusion.

- Vapor migration ease. Buildings overlying vadose zones made up of coarse geological materials (e.g., gravel, boulders) would generally be expected to have a greater potential for vapor intrusion than buildings overlying vadose zones comprised of fine-grained materials (e.g., silts, slays), provided significant preferential pathways (e.g., geologic fractures, utility corridors) are not present in the fine-grained layers.

Interviews and building surveys during development of the investigation work plan (or during the preliminary analysis – see Section 5) also can provide useful information for prioritizing buildings, when phased testing is chosen or indicated. Sections 6.3 and 6.4 provide additional examples of survey information that can support planning, in addition to supporting data interpretation.

In situations where “higher-priority” buildings and locations are investigated initially, investigation of locations of other buildings may still be warranted, for example, to ensure that the CSM is complete and accurate and that variability in the subsurface conditions and building conditions is understood. There usually is substantial spatial variability in the concentrations of subsurface vapors, caused by heterogeneities in the subsurface materials and other factors that can result in spatial variability in indoor air concentrations. Additionally, building-specific characteristics and occupants’ activities that affect building ventilation will vary from building to building, further adding to the temporal variability in indoor air concentrations. Therefore, it may be difficult to identify *a priori* a “representative” or “reasonable worse case” building or group of buildings, when it is determined that sampling all buildings is not practical.

When sampling all buildings is not practical, but other lines of evidence suggest that vapor intrusion may be occurring, the site management team may wish to consider installing engineered exposure controls for vapor intrusion mitigation in buildings without baseline indoor air data (i.e., building mitigation as an early action – see Section 9.0).

6.2.3 Planning for Community Involvement

Community involvement is an important component of any vapor intrusion investigation. EPA generally recommends that a community involvement or public participation plan (see Section 10.1) be developed or refined while planning a vapor intrusion investigation. Proper and sustained community outreach and engagement efforts are critical to effectively implementing work plans for vapor intrusion investigations, particularly when sampling in a home or workplace or on private property is involved. Resuming and conducting community involvement at legacy sites can be particularly complex. The site planning team is highly encouraged to consult with appropriate EPA colleagues experienced in community outreach and involvement efforts and utilize available EPA planning resources, including those discussed in Section 10.0.

6.3 Characterize the Vapor Intrusion Pathway

As discussed in Section 2.0, the vapor intrusion pathway entails emanation of volatile chemicals from a source in a vapor form that migrates in the vadose zone, accumulates underneath building foundations, and enters buildings through openings and conduits. As a result, detailed vapor intrusion investigations designed to develop or enhance the CSM for a specific site will typically address one or more of the following objectives, often in phases:

- Characterize the nature and extent of potential sources of vapors.
- Characterize the migration paths between vapor sources and buildings (potential “receptors”).
- Assess building(s) and potential susceptibility to soil gas entry.
- Confirm the presence of a site-related contaminant(s) in the indoor environment.
- Assess the potential contributions of indoor sources to concentrations of hazardous vapors in indoor air.

These objectives are described in the following subsections for purposes of identifying the primary lines of evidence typically developed and evaluated for each objective and describing how the objectives fit together in developing and enhancing the CSM for a specific site and characterizing vapor intrusion potential. This information is provided to assist the site planning team in selecting and sequencing objectives for vapor intrusion investigations. The order of presentation is not intended to convey a suggested sequencing of objectives; rather, it follows the presentation of the conceptual model of vapor intrusion.

6.3.1 Characterize Nature and Extent of Vapor Sources

Investigations to characterize the nature and delineate the extent of potential sources of vapors may rely upon the results of groundwater sampling, soil sampling, or soil gas sampling, as dictated by the site-specific source(s) and subsurface conditions.

Groundwater Sources:

Where contaminated groundwater is a vapor source located near buildings, EPA recommends that groundwater observation wells (i.e., monitoring wells) be installed at strategic locations and used to assess groundwater flow and contaminant concentrations. The extent of groundwater contamination should be verified through groundwater sampling and analysis.[49] Groundwater samples obtained from the uppermost portion of the aquifer that underlies the study area of interest (i.e., where buildings are located) are recommended for establishing representative source concentrations. For this purpose, wells that are screened across the water table interface are preferred and samples should be collected as close as possible to the top of the water table using approved sampling methods designed to minimize loss of volatiles while sampling (EPA 2002a, EPA-ERT 2001a).[50] Ideally, the plume should be shown as stable or shrinking (i.e., is not migrating or rising in concentration, including hazardous byproducts of any biodegradation), through multiple rounds of sampling.

For purposes of assessing vapor intrusion for specific buildings, groundwater samples from wells near buildings are generally recommended over those from distant wells. Interpolation of the results obtained from two or more wells in the uppermost portion of the aquifer may be warranted for these purposes when the spatial pattern suggests significant lateral gradients in contaminant concentrations within the area of interest. However, for purposes of determining whether groundwater poses negligible risk of vapor intrusion on an area-wide basis, it may be more appropriate to utilize sampling results for the most greatly impacted well within the area of interest.

In addition, EPA generally recommends that a soil gas sample be collected immediately above the groundwater table (and above the capillary fringe) (i.e., “near-source” soil gas sample) to help characterize the vapor source.

Vadose Zone Sources:

Where contaminated soil or NAPL in the vadose zone is a vapor source, soil sampling using coring techniques for sample retrieval or using sensors, such as a membrane interface probe, can be used to delineate the extent of contamination. Bulk soil concentration data

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[49] Although a soil gas survey can also be employed as a screening tool to assist with the delineation of a plume of contaminated groundwater, EPA recommends that plume delineation ultimately be supported by the collection and analysis of confirmatory groundwater samples at appropriate locations.

[50] If available groundwater data do not meet these criteria, the site data review team should judge whether they are nevertheless representative of potential vapor source concentrations emanating from groundwater.

can be used in a qualitative sense for this purpose. For example, high soil concentrations generally would indicate impacted soil. Unfortunately, the converse is not always true. Non-detect results for soil samples cannot be interpreted to indicate the absence of a subsurface vapor source, because of the large uncertainties associated with measuring concentrations of volatile contaminants introduced during soil sampling, preservation, and chemical analysis.

Alternatively or in addition, a soil gas survey can be used to locate the primary source zone and delineate the areal and vertical extent of the vapor-affected area. Generally, EPA recommends that the soil gas survey include a soil gas sample collected immediately above each contaminant source in the vadose zone (i.e., "near-source" soil gas samples) to help characterize the vapor source.

These sampling options are generally coupled with an understanding of the site-specific subsurface conditions that control the location and extent of contamination (e.g., geologic properties, including stratigraphy and level of heterogeneity; hydrogeologic conditions). Such understanding is generally developed by interpreting the data obtained through borehole logging (i.e., visually inspecting soil cores and determining soil texture) or geophysical tools.

Sample locations should generally be of sufficient density to adequately account for spatial variability and heterogeneity in subsurface conditions. EPA generally recommends consulting with individuals who have expertise in characterizing subsurface environmental conditions (e.g., a geologist) when determining appropriate sampling locations and spacing.

When combined with the data demonstrating that the property reflects the conditions and assumptions of the generic model invoked in the VISLs (see Section 6.5.1), groundwater and "near-source" soil gas samples can be compared to medium-specific screening levels to develop an initial quantitative perspective about the potential level of exposure and risk posed by vapor intrusion. Section 6.5 provides additional information and guidance about risk-based screening of vapor source concentrations.

6.3.2 Characterize Vapor Migration in the Vadose Zone

Investigations seeking to characterize vapor migration in the vadose zone generally entail, at a minimum, a soil gas survey. Because soil gas concentrations can exhibit considerable spatial variability,[51] EPA generally recommends that soil gas surveys collect soil gas samples at multiple locations and depth intervals between the vapor source and buildings (potential "receptors"). The soil gas survey may include samples collected immediately outside the building ("exterior soil gas") at various depths or several depth intervals, as well as immediately

[51] Modeling of idealized scenarios provides additional demonstrations about spatial variability of soil gas concentrations. For example, vertical profiles of soil gas concentration can be very different underneath buildings compared to locations exterior to the building and soil gas concentrations may not be uniform laterally, particularly in the vicinity of the building, even when the vapor source is a laterally extensive plume of contaminated groundwater (EPA 2012b). These simulation results indicate why EPA recommends that soil gas generally be sampled in multiple sampling locations, when assessing subsurface vapor migration pathways.

beneath it (sub-slab soil gas sampling).[52] Where applicable, crawl space air sampling may be conducted.

Generally, EPA recommends that the soil gas survey include a "near-source" soil gas sample collected immediately above each source of contamination to help characterize the vapor source (see Section 6.3.1). If any shallow soil gas samples are collected, EPA recommends they be collected as close as possible to the building and at depths below the respective building foundation and no less than five feet below ground surface, depending on site-specific conditions.

To characterize subsurface migration in the vadose zone, soil gas survey data are generally coupled with an understanding of the site-specific subsurface conditions that influence vapor migration and attenuation (e.g., geologic properties, including stratigraphy and level of heterogeneity; hydrologic conditions, including groundwater elevation and soil moisture; and biological properties, including availability of oxygen to support aerobic biodegradation).[53] Such geologic understanding is generally developed by interpreting the data obtained through borehole logging and geophysical tools. Hydrologic conditions can be characterized by analyzing soil samples for porosity and moisture content and by hydrologic modeling. An intensive soil gas survey to establish current vertical profiles for contaminant vapors and oxygen (and, in some cases, biodegradation products) may be able to demonstrate that biodegradation is responsible for attenuating vapor migration to a greater extent than can be attributed to advection and diffusion in the vadose zone.[54]

When conducted contemporaneously for multiple buildings, a soil gas survey and characterization of the vadose zone can help identify distances from subsurface vapor sources beyond which threats from vapor intrusion are not reasonably expected, as mentioned in Section 6.2.1. At sites with a limited number of potentially affected buildings, it may be feasible to characterize the subsurface vapor migration near and surrounding all of them. However, at sites where a large number of buildings may be affected, this approach is not likely to be feasible; in these cases, EPA generally recommends that the site manager seek the advice of a geologist familiar with the site-specific subsurface conditions to help guide selection of appropriate sampling locations and assess whether "representative" or "reasonable worse case" locations can be identified, as appropriate to the objectives of the investigation. Because there usually is substantial spatial variability in the concentrations of subsurface vapors, caused partially by heterogeneities in the subsurface materials, it may be difficult to identify *a priori* locations that are either "representative" or are "reasonable worse case" subsurface conditions.

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[52] Spacing of soil gas sampling locations should generally consider the extent and location of the subsurface vapor source, distance between the building and the source, and other site-specific factors.

[53] As noted in Section 2.0, vapor migration in the vadose zone can be impeded by several factors, including soil moisture, low-permeability (generally fine-grained) soils, and biodegradation. Significant characterization of the vadose zone may be needed to demonstrate that the applicable geologic, hydrologic, and biologic features are laterally extensive over distances that are large compared to the size of the building or the extent of vapor contamination at a specific site.

[54] In this context, mathematical modeling can be employed to characterize vapor migration attributable to advection and diffusion in the vadose zone.

Subsurface investigations of vapor intrusion should also generally include an evaluation of utility corridors, which can facilitate unattenuated vapor transport over longer-than-anticipated distances or migration of NAPLs towards and into buildings that are serviced by the utility. Public and facility records are often useful sources of information about utility locations, which may provide maps, "as built diagrams," or construction specifications. Depending upon the CSM, sampling of vapors within the utility corridor (or within a sewer, if applicable) may be warranted to characterize vapor migration in the subsurface (or characterize a secondary source of vapors – see Sections 6.3.1 and Section 2.1).

When combined with other data, as discussed further in Section 7.3, information about subsurface vapor migration can support determinations that the vapor intrusion pathway is complete under current conditions or may be complete under future conditions. When combined with other lines of evidence, information about subsurface vapor migration can support determinations that the vapor intrusion pathway is not complete under current conditions, as discussed further in Section 7.3.

When evaluating subsurface vapor migration and attenuation in locations where buildings do not exist, it is important to recognize that the conditions in the vadose zone and subsurface vapor concentrations may be changed as a result of constructing a new building and/or supporting infrastructure. For example, the moisture content may decrease and the moisture profile change in the vadose zone as a result of reduced infiltration of rainwater. The permeability to vapor flow in the vadose zone may be altered in the foundation vicinity due to construction. Finally, the future presence of extensive surface covers and/or utility corridors may also modify the vertical and horizontal profile of vapor concentrations in the subsurface. As a result, EPA recommends that lines of evidence in addition to a soil gas survey (e.g., modeling) be developed and considered to support any determination that a future building will not be subject to vapor intrusion or will not pose unacceptable health risks for occupants. Owing to the potentially unpredictable plans for building construction and site redevelopment, as well as potentially unpredictable changes in the transitory soil characteristics (e.g., soil moisture) and subsurface vapor concentrations, institutional controls (e.g., to require a confirmatory evaluation of the vapor intrusion pathway when new buildings are constructed) may be warranted for this situation.

6.3.3 Assess Building Susceptibility to Soil Gas Entry

When elevated concentrations of vapor-forming chemicals accumulate in the soil gas immediately underneath the foundation, surrounding the basement, or within the crawl space of a vulnerable building, then soil gas entry (i.e., vapor intrusion) can lead to unacceptable levels of subsurface contaminants in indoor air. As discussed in Section 2.3, soil gas can enter a building when vapor entry routes are present and driving forces favor advection of air from the subsurface into indoor air. Single-family detached homes can generally be presumed susceptible to soil gas entry, unless a mitigation system (e.g., radon mitigation system) is present and operating as intended.

EPA recommends that more than one line of evidence be employed to assess susceptibility to soil gas entry, when this objective is selected as part of a site-specific investigation plan for vapor intrusion assessment. Vulnerability to soil gas entry can be assessed for a specific building by using any of several methods, including:

- Concurrently monitoring indoor air samples for presence of radon and finding radon in indoor air at levels greater than outdoors.[55]

- Employing a photoionization detector (PID) or other real-time in-field device, capable of detecting parts per billion by volume (ppbv) levels, to directly survey suspected locations of soil gas entry (e.g., utility penetrations, sumps) and finding elevated readings of vapors.

- Conducting a visual inspection for cracks and holes in concrete foundation slabs or basement walls. (Openings for soil gas entry will not necessarily be visible or accessible for inspection, so the absence of visible openings, by itself, is insufficient to demonstrate that a building is not susceptible to soil gas entry.)

- Monitoring pressure differences between the building and subsurface environment to assess the effects of the heating, ventilation, and air-conditioning (HVAC) systems.

- Injecting tracers, such as sulfur hexafluoride or helium, into the subsurface at selected concentrations and subsequently finding it in indoor air samples.

Certain complementary information obtained for the building, as identified in Section 6.4.1, can also support such assessments. Relevant information includes the operating characteristics of HVAC systems.

In many commercial buildings, the HVAC system brings outdoor air into the building, potentially creating building over-pressurization relative to the outdoor environment. When the building is over-pressurized, vapor intrusion potential is diminished because a driving force for soil gas entry should not exist over at least a portion of the building foundation.[56] When the subsurface vapor sources underneath or near such buildings have significant potential to pose a vapor intrusion threat, it may be useful to assess susceptibility to soil gas entry and diagnose vapor intrusion (see Sections 6.3.4 and 6.4.1) in such buildings under conditions when the HVAC system is not operating. (In addition, indoor air testing could be conducted during periods when the HVAC system operates with diminished flows, such as weekends or evenings.) The results of such testing can be used to support decisions about building mitigation, monitoring, and institutional controls as part of a vapor intrusion remedy. For example, if the results indicate susceptibility to soil gas entry when the HVAC system is not in operation and vapor intrusion under these conditions has the potential to pose a health concern, then the building may warrant engineered exposure controls and/or future monitoring (e.g., continuous monitoring of

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[55] Naturally occurring radon may serve as a tracer to help identify those buildings that are more susceptible to soil gas entry than others. Buildings with radon concentrations greater than levels in ambient air are likely susceptible to soil gas intrusion and would likely be susceptible to other subsurface vapors. On the other hand, the radon concentration in a building is <u>not</u> generally expected to be a good quantitative indicator of indoor air exposure concentrations of vapor-forming chemicals. Hence, radon measurement is not generally recommended as a proxy for directly measuring vapor-forming chemicals in indoor air. Among other factors, the distribution of radon-emanating rock and soil and the spatial and temporal variability of their source strength are generally expected to be very different than the distribution and source strength variability for subsurface sources of chemical vapors.

[56] Over-pressurization may not be uniform throughout a building, particularly in large buildings. It should not be assumed that any over-pressurization in portions of a building will necessarily mitigate all openings for soil gas entry.

the pressure gradient across the foundation or indoor air testing), which may be enforceable through an IC (see Section 8.6). Similarly, buildings with pre-existing radon mitigation systems, which overlie or are near subsurface vapor sources, could be tested under conditions where the radon mitigation system is not operated to support decisions about building mitigation, monitoring, and institutional controls as part of a vapor intrusion remedy.

6.3.4 Evaluate Presence and Concentration of Subsurface Contaminants in Indoor Air

Indoor air sampling (see Section 6.4.1) using time-integrated sampling methods or grab samples can confirm the presence, if any, of a site-related, subsurface contaminant(s) in the indoor environment. When combined with data characterizing subsurface vapor migration and demonstrating the building is (or is not) susceptible to soil gas entry, indoor air sampling data can support determinations that the vapor intrusion pathway is (or is not) complete for a given building, as discussed further in Section 7.3. When conducted contemporaneously in multiple buildings, indoor air sampling can, in concert with soil gas survey data and data delineating subsurface vapor sources, help identify the boundaries of "vapor intrusion inclusion zones" (i.e., neighborhood areas within which buildings are known or suspected to have indoor air concentrations of subsurface contaminants arising from vapor intrusion (see Section 6.2.1)).

Indoor air sampling is most commonly conducted using time-integrated sampling methods to estimate exposure concentrations for building occupants, which may include contributions from "indoor" or ambient air sources of these chemicals (see Section 2.5). For example, time-integrated concentrations of hazardous vapors in samples of indoor air can be compared to appropriate, risk-based screening criteria (see Section 6.5) to support inferences about risks posed by vapor-forming chemicals found in the subsurface environment.[57]

When sampling indoor air or sub-slab soil gas to estimate exposure concentrations arising from vapor intrusion, EPA generally recommends removing potential indoor sources of vapor-forming chemicals (see Section 2.5 and 6.4.1) from the building to strive to ensure that the concentrations measured in the indoor air samples are attributable to the vapor intrusion pathway. However, even after removing indoor sources, their effects may linger depending on source strength, relative humidity in the building, and the extent to which the contaminants have been absorbed by carpets and other fabrics or "sinks." In addition, field experience suggests that it may not be possible to remove all indoor sources. It may be particularly impractical to do so in industrial settings where vapor-forming materials are used or stored.

6.3.5 Identify and Evaluate Contributions from Indoor and Ambient Air Sources

To support evaluations of sources of indoor air concentrations, EPA recommends that the CSM identify known or suspected indoor sources of the volatile chemicals also found in the subsurface (see Section 2.5) and characterize ambient air quality (see Section 6.4.2) in the site vicinity for these same chemicals. Key supporting information includes: (1) the locations and

[57] In certain cases, depending in part on the results (e.g., concentrations exceed risk-based screening levels), indoor air sampling data may be a sufficient basis for supporting decisions to undertake pre-emptive mitigation/early action (see Section 9.0) in lieu of additional rounds of sampling and analysis or an evaluation of the contribution of background sources to indoor air concentrations.

types of known or potential indoor sources; (2) information about outdoor sources, such as nearby commercial or industrial facilities and mobile sources (e.g., cars, trucks, and other equipment); and 3) data on the local ambient air quality.

Grab (essentially short-duration) samples of indoor air, as described in Section 6.4.1, can be useful for identifying indoor sources of vapors. Indoor air concentrations obtained using time-integrated sampling methods are generally needed, however, to distinguish contributions to indoor air concentrations from vapor intrusion versus indoor and ambient air sources.

If the subsurface vapor sources are comprised of multiple vapor-forming chemicals and the subsurface source and distribution for these chemicals are similar, then time-integrated sampling methods can be used to determine whether concentrations of hazardous vapors in indoor air are primarily due to indoor sources. Specifically, concurrent sub-slab soil gas can be collected with indoor air samples.

> Results indicating vapor intrusion as primarily responsible for indoor air concentrations. The predominant vapor-forming chemicals and their relative proportions in indoor air and sub-slab vapor samples would be expected to be similar and their concentrations in sub-slab soil gas would be expected to be higher than in indoor air, if vapor intrusion is primarily responsible for indoor air concentrations. If recalcitrant (i.e., not subject to biodegradation in the vadose zone), the predominant vapor-forming chemicals and their relative proportions in the subsurface vapor source should also be similar if vapor intrusion is primarily responsible for indoor air concentrations.

> Results indicating indoor sources as primarily responsible for indoor air concentrations. Conversely, if significant concentrations of a contaminant are detected in indoor air, but are not present or barely present in sub-slab soil gas samples (or representative samples of the subsurface vapor source), then the presence of this contaminant in indoor air may not arise from the vapor intrusion pathway, but rather from indoor sources or other background sources.

Likewise, concurrent outdoor (ambient) air samples can be collected, in addition to indoor air samples. If the predominant vapor-forming chemicals and their relative proportions in indoor air and outdoor (ambient) air are similar, then vapor intrusion may not be primarily responsible for indoor air concentrations (particularly if the predominant vapor-forming chemicals and their relative proportions in the subsurface vapor source (e.g., groundwater or soil) are dissimilar).

Current levels of volatile chemicals in ambient air and in indoor air due to indoor and ambient air sources may be lower than those observed historically, due to regulations and business practices fostering less use of toxic, vapor-forming chemicals in consumer products and industrial processes. As a result, EPA does not recommend the use of generic values of historic background concentrations, even those cited in peer-reviewed publications, to characterize current levels in any building. Rather EPA recommends that site-specific data (e.g., sub-slab, indoor air and ambient air sampling data) be obtained, and evaluated, as described above, when the investigation objectives include demonstrating that indoor air concentrations arise from indoor or ambient air sources.

On the other hand, if measured indoor air concentrations are found to greatly exceed the historic range of background levels, there is a greater likelihood that the indoor air concentrations are the result of vapor intrusion. EPA has compiled and published an evaluation of studies pertaining to indoor air concentrations of volatile organic compounds in North American residences in 1990-2005 (EPA 2011a), which can be employed to identify whether measured indoor air concentrations are in the historic range of background concentrations; if so, then EPA recommends planning additional site-specific investigations aimed at distinguishing between vapor intrusion and indoor and ambient air as contributors to indoor air concentrations.

6.3.6 Select, Prioritize, and Sequence Investigation Objectives

Site-specific investigations of potential vapor intrusion frequently begin with pursuing one or more of the foregoing objectives presented in Sections 6.3.1 through 6.3.5. Criteria potentially warranting consideration by the site planning team when making decisions about prioritizing and sequencing investigation objectives include: site scenario (see Section 6.1); data gaps in the CSM (see Section 5.4); and relationships with and perspectives of the owners and occupants of potentially impacted buildings.

Characterizing vapor sources (Section 6.3.1), characterizing subsurface vapor migration (Section 6.3.2), and evaluating the presence of subsurface contaminants in indoor air (Section 6.3.4) – are frequently candidates for an initial objective and each can be pursued separately. For example, characterizing vapor sources (Section 6.3.1) may be a useful initial choice when responding to an initial report about a release of hazardous, vapor-forming chemicals to the subsurface from a commercial or industrial operation or when buildings do not exist currently, but are expected in the future. Characterizing vapor sources may also be a useful initial choice when building owners or occupants are reluctant to grant access for indoor air testing. In this situation, the site planning team may need to pursue subsurface investigations more intensely to characterize vapor intrusion potential before being granted building access. When responding to reports of odors in buildings or addressing vapor intrusion for the first time as part of a periodic review of a remedial or corrective action for contaminated groundwater, testing indoor air (Section 6.3.4) may be a useful initial objective. In a different scenario, characterizing subsurface vapor migration (Section 6.3.2) may be a useful starting point when addressing sources that are comprised of potentially biodegradable chemicals or that are suspected to occur below an extensive geologic layer that might impede upward diffusive migration. For large buildings with HVAC systems that may over-pressurize the interior relative to the subsurface environment, EPA generally recommends: a building assessment early in the investigation, which obtains and weighs the complementary information identified in Section 6.4.1, to support investigation planning; and an evaluation of susceptibility to soil gas entry under conditions when the HVAC system is not operating (see Section 6.3.3).

The investigation objectives described in Sections 6.3.1 through 6.3.5 may, in some cases, be conducted iteratively with increasing complexity as the investigation proceeds and the CSM is refined. For example, grab (essentially short-duration) samples of indoor air, as described in Section 6.4.1, can be useful for identifying indoor sources of vapors while potential background sources (e.g., household or commercial cleaning products) are surveyed and before indoor air is tested using time-integrated sampling methods to estimate exposure concentrations. More advanced methods of distinguishing contributions to indoor air might be utilized in intermediate phases of the investigation under such an iterative approach.

6.4 General Principles and Recommendations for Sampling

Sampling of indoor air, outdoor air, soil gas, and groundwater and analysis for vapor-forming chemicals can play an important role in vapor intrusion investigations for one or more of the objectives identified in Section 6.3. This subsection summarizes for indoor air, outdoor air, sub-slab soil gas, exterior soil gas, and groundwater the following:

- Principal methods for collecting samples.
- Potential uses of the resulting sampling data.
- Recommended practices for sample collection.
- Unique or frequently encountered logistical issues.

Soil and NAPL sampling also may be used to characterize the nature and extent of subsurface vapor sources (see Section 6.3.1). Information about soil sampling can be found in EPA-ERT (2001b). However, because of the large uncertainties associated with measuring concentrations of volatile contaminants introduced during soil sampling, preservation, and chemical analysis, bulk soil (as opposed to soil gas) sampling and analysis is not currently recommended for estimating the potential for vapor intrusion to pose unacceptable health risks in indoor air. In addition, there are uncertainties associated with soil partitioning calculations.

EPA recommends that the site planning team ensure that the sampling data will meet the site-specific data quality needs. This entails ensuring that the sampling and analytical methods are capable of obtaining reliable analytical detections of concentrations less than project-appropriate, risk-based screening levels (e.g., VISLs). It can also entail identifying and utilizing appropriate sampling locations and durations and addressing spatial and temporal variability to fulfill the specific objectives of the investigation, which may include obtaining data to characterize the potential human exposure in a building(s). The number and types of samples used at a specific site should be decided by the planning and data review team based on the CSM, the objectives of the investigation, and other site-specific information.

The sampling duration depends on the type of medium being sampled (for example, soil gas, sub-slab soil gas, and indoor or outdoor air) and analytical methods (for example, Method TO-15). Some of the key recommended considerations are provided in the following subsections. Several rounds of sampling are often needed to develop an understanding of temporal variability.

6.4.1 Indoor Air Sampling

Indoor air sampling results: are needed to assess the presence and level of risk posed by vapor-forming chemicals in indoor air (see Sections 6.3.4 and 7.4); and can be useful in diagnosing whether vapor intrusion is occurring (see Sections 6.3.3, 6.3.5, and 7.3). These two uses of indoor air sampling in vapor intrusion investigations are discussed further below with recommended methods for each. As discussed further in Sections 8.4 and 8.7, indoor air sampling may also be useful for supporting performance evaluations of vapor intrusion mitigation systems and verifying the health protectiveness of subsurface remediation systems.

A potential shortcoming of indoor air testing is that indoor sources and outdoor sources unrelated to subsurface contamination – "background" – may contribute to the presence of volatile chemicals in occupied buildings (see Section 2.4), particularly if these sources cannot be removed from the building prior to sampling indoors. This shortcoming of indoor air testing is unavoidable when the subsurface environment contains the very same volatile chemicals that originate in indoor air due to background sources, which is common for some chemicals and relatively rare for others (EPA 2011a). In this circumstance, additional lines of evidence, possibly including special procedures and analyses, should be evaluated to distinguish background contributions from those originating from vapor intrusion (see Section 6.3.5).

After discussing recommended sampling methods and practices for the primary uses of indoor air sampling data, this sub-section concludes by discussing:

- Recommended measures to reduce the impact of indoor sources of vapor-forming chemicals.
- Recommended approach to establishing analyte lists for indoor air samples.
- Complementary, building-specific data that can be collected contemporaneously while indoors.

<u>Estimate Human Exposure Levels.</u> Indoor air sampling and analysis provide the most direct approach to estimating concentrations of toxic, volatile chemicals in indoor air to which building occupants can be exposed. For these purposes, time-integrated sampling methods are generally recommended for indoor air, since indoor air concentrations can be temporally variable within a day and between days, seasons, and years.

For many years, evacuated canisters have been the industry standard for collecting time-integrated samples. Typically, indoor air samples are collected over a 24-hour period in residences or over an 8-hour period (or workday equivalent) in commercial and industrial settings, when using these devices.[58] Although passive diffusion samplers have been less commonly used to quantify indoor air concentrations, their use may grow as a result of recent demonstrations that they can yield results comparable to those obtained using evacuated canisters (EPA-Region 9 2010; EPA 2012g; Odencrantz et al. 2009; Odencrantz et al. 2008), and a recognition that they may be less intrusive for some building owners and occupants and more convenient for field staff (EPA-Region 9 2010). Passive diffusion samplers are also capable of being deployed for longer durations than evacuated canisters, thereby providing a more economic means of obtaining average indoor air concentrations over longer periods of exposure.

For a typical-size residential building or a commercial building less than 1,500 square feet, EPA recommends that the site teams generally collect one time-integrated sample in the area directly above the foundation floor (basement or crawl space) and one from the first floor living or

[58] Two (or more) large canisters can be connected together to allow collection of time-integrated samples over longer durations, which is generally desirable for estimating long-term average exposure levels.

occupied area, at least for the initial sampling round. In general, samples should be collected at the breathing zone level for the most sensitive exposed population.

Situations that should trigger discussions about the number of sample locations per building include: (1) very large homes or buildings;[59] (2) multi-use buildings, particularly ones with segmented areas that are occupied by different populations (e.g., day care with young children versus office with adult workers) or have different occupancy patterns over time. Additional samples may be warranted, depending on internal building partitions, HVAC layout, contaminant distribution in the subsurface, and occurrence of observable locations of potential soil gas entry (e.g., basement sumps or drains, relatively large holes or spaces in the foundation floor, entry points for utilities). Closed rooms located below ground may have appreciably higher contaminant concentrations originating from vapor intrusion. Closed rooms may warrant sampling to characterize the reasonably maximum exposure levels, if occupied, or to diagnose vapor intrusion (e.g., see below), even if not occupied.

More than one round of indoor air sampling is generally recommended in order to characterize exposure levels in indoor air, because of the temporal variability of indoor air concentrations, which reflects time-dependent changes in soil gas entry rates, exchange rates, intra-building mixing, among other factors. Also, multiple sampling events generally are considered necessary to account for seasonal variations in climate and changes in the habits of building occupants.[60] In many geographic areas, indoor air sampling during the heating season, when stack effects are generally more significant, may yield higher indoor air concentrations than at other periods. Another scenario that may yield higher indoor air concentrations is when a building is sealed and the ventilation system is not operating.

When sampling indoor air or sub-slab soil gas, EPA generally recommends removing potential indoor sources of vapor-forming chemicals (see Section 2.5) from the building to strive to ensure that the concentrations measured in the indoor air samples are attributable to the vapor intrusion pathway. Field experience in residential settings suggests that it may not be possible to remove all sources. It may be particularly impractical to do so in industrial settings where vapor-forming materials are used or stored. After removal of indoor sources, their effects may linger longer depending on source strength, relative humidity inside the building, and the extent to which the contaminants have been absorbed by carpets and other fabrics or “sinks.” In residential settings, EPA generally recommends that potential indoor sources be removed from the structure and stored in a secure location at least 24 to 72 hours prior to the start of sampling, based on an approximate air exchange rate of 0.25 to 1.0 per hour in residential buildings.

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[59] Larger commercial and residential buildings (e.g., multi-family residences) may require additional discussion with the site planning team and perhaps a statistician to select the appropriate number and placement of indoor air samples to meet DQOs.

[60] More than one round and often several rounds are needed to develop an understanding of temporal variability of indoor air concentrations. Given EPA’s over-arching duty to protect human health and the disruption to building owners and occupants caused by indoor air sampling, risk managers may choose to pursue pre-emptive mitigation (i.e., early action) at some buildings (see Section 9.0) rather than, for example, conduct multiple rounds of sampling over a few years to establish a better estimate of long-term average exposure concentration.

Diagnose Vapor Intrusion and Background Sources. When access is granted for indoor air sampling, EPA generally recommends concurrently collecting sub-slab soil gas and outdoor (ambient) air over similar durations using the same methods. Comparing these results to each other and to results for subsurface vapor sources can foster insights and support findings about the relative contribution of vapor intrusion and background sources to indoor air concentrations (as described in Section 6.3.5). In this case, time-integrated sampling methods are generally recommended for indoor air, because concentrations of vapor-forming chemicals can vary significantly over time.

Grab (essentially short-duration) samples of indoor air can, however, be useful for confirming the presence of a subsurface contaminant in indoor air (see Section 6.3.4), identifying indoor sources of vapors (see Section 6.3.5), and identifying openings for soil gas entry into buildings (see Section 6.3.3). These samples can be analyzed with EPA's mobile Trace Atmospheric Gas Analyzer (TAGA), field-portable gas chromatographs, or mass spectrometers (EPA-ERT 2012). For identifying indoor sources or openings for soil gas entry, one round of grab sampling of indoor air may be sufficient. Grab samples can also provide a convenient and less intrusive means of confirming the presence, if any, of a site-related, subsurface contaminant(s) in the indoor environment. For this purpose, EPA generally recommends collecting one sample directly above the foundation floor (basement or crawl space) and one from the first floor living or occupied area.

An individual grab sample is not reliable, however, for purposes of demonstrating that vapor intrusion is not occurring in a specific building, because indoor air concentrations can exhibit significant temporal variability. In general, EPA recommends collecting multiple time-integrated samples to support any such building-specific determination.

Indoor air samples can also be concurrently collected for radon testing, which may be useful in evaluating building susceptibility to soil gas entry (see Section 6.3.3).

Evaluate and Develop Analyte Lists. EPA recommends the site planning and data evaluation team limit chemical analyses to those vapor-forming chemicals known (based upon subsurface contaminant characterization) or reasonably expected (based upon site history) to be present in the subsurface environment. For example, if the site history and reliable subsurface sampling data do not identify benzene as a subsurface contaminant, it would be appropriate for site managers to exclude benzene as a target analyte for indoor air samples. Benzene could originate indoors as a result of a car, lawnmower, or snow blower in a garage. In this hypothetical case, benzene would not typically be amenable to reduction by vapor mitigation systems or subsurface remediation efforts. In fact, requesting an extensive list of analytes that are not related to subsurface contamination may unnecessarily complicate risk communication if indoor air testing reveals volatile chemicals unrelated to vapor intrusion.

Collect Complementary Data While Indoors. EPA recommends that the following complementary data be gathered by observation, interviews, or reports (e.g., mechanical test-and-balance reports) while buildings are sampled to analyze indoor air:

- Building Occupancy

  - Characteristics and locations of building occupants (e.g., residents, including children; expectations for presence of general public in commercial or industrial settings; presence of multiple exposure units – due to different uses or activities and occupants – within a building).

  - Hours of building occupancy under current conditions (and reasonably expected future conditions, as appropriate), particularly for a nonresidential setting. This information is pertinent to the risk assessment and data evaluation and should generally factor into the sampling duration needed to represent indoor air exposure.

- Susceptibility to Soil Gas Entry Under Current Conditions

  - Presence and operation of a mitigation system, which would generally be expected to mitigate intrusion of vapor-forming chemicals even if designed for radon.

  - Physical conditions that indicate potential openings to soil gas entry (e.g., potential conduits, such as cracks or floor drains; presence of structures such as utility pits, sumps, and elevators; basements or crawl spaces; modifications to the original foundation).

  - Any areas with significant under-pressurization, relative to the outdoors. (As noted in Section 2.3, building under-pressurization relative to the subsurface provides a driving force for soil gas entry.)

- Building Ventilation, Heating, and Cooling

  - Building ventilation, including zones of mechanical influence and stagnation. As noted in Section 2.3, greater ventilation typically results in smaller vapor concentrations in indoor air. Any non-ventilated or passively ventilated rooms (such as mechanical rooms) may be subject to greater accumulation of vapors. For commercial and industrial buildings, each distinct zone of influence may warrant sampling, when indoor air testing is selected as part of a site-specific investigation plan for vapor intrusion assessment.

  - Operating characteristics of HVAC systems. In many commercial buildings, the HVAC system brings outdoor air into the building, potentially creating building over-pressurization relative to the outdoor environment. Any areas with significant over-pressurization, relative to the outdoors, should be noted.

- Indoor and Outdoor Sources of Vapor-Forming Chemicals

  - Chemicals and consumer products used or stored within the building that can act as potential sources of toxic vapors. Vapor-forming chemicals are used in many commercial and most industrial buildings. As noted in Section 2.5, consumer products that can emit vapors may be common in residential buildings. In some circumstances, a PID, capable of detecting ppbv levels, can be used to directly survey the building for locations with vapor-forming chemicals and materials; however, the PID may not be sensitive enough for very low concentration sources. More sensitive options may include use of the HAPSITE gas chromatograph/mass spectrometer or the TAGA Mobile Laboratory (EPA-ERT 2012).

  - HVAC systems that bring outdoor air into the building potentially bring contaminated outdoor air into the building, depending on the location of the vent and exhaust with regard to other spaces. For example, HVAC intakes adjacent to or near a dry-cleaning facility may introduce toxic vapors of the dry-cleaning solvent into the building.

- Presence and operation of any indoor air treatment system (e.g., in-line carbon adsorption) that can reduce indoor exposure levels of vapor-forming chemicals.

In general, EPA recommends that the complementary information be collected during investigation planning and scoping to help decide where to sample and prioritize or sequence buildings for testing. Then, the information can be confirmed during indoor sampling.

In some cases, contaminated groundwater seeps into or actively collects in the building (for example, in sumps), possibly serving as a direct source of vapors. It may be appropriate to collect water samples concurrently with indoor air (and any sub-slab) samples in these circumstances.

6.4.2 Outdoor Air Sampling

Outdoor air concentration data can be useful in identifying potential contributions to indoor air concentrations from ambient air sources (see Section 6.3.5). Therefore, EPA generally recommends collecting ambient air samples using similar sampling and analysis methods, whenever indoor air samples are collected. Normally, one or two outdoor air sample locations should be sufficient to characterize the conditions surrounding a single or a few buildings.[61] Additional outdoor air samples may be warranted if the investigation is assessing multiple buildings over a wide area. Sample locations should be designed to characterize representative conditions in the absence of site-related subsurface contamination (i.e., avoid collecting ambient air samples near locations of known or suspected chemical release(s), including any atmospheric releases from remediation equipment). It also is suggested that observable potential outdoor sources of pollutants (e.g., air emissions from nearby commercial or industrial facilities) be recorded during all building surveys.

EPA recommends that ambient air samples generally be collected over the same sampling period as indoor air so contaminant concentrations can be compared between media. To facilitate such a comparison for residential buildings, EPA generally recommends beginning ambient air sampling at least one hour, but preferably two hours, before indoor air monitoring

[61] For buildings where outdoor air is mechanically brought into the building, an outdoor sample may be co-located near the HVAC intake.

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begins and continuing to sample until at least 30 minutes before indoor monitoring is complete. EPA recommends this practice because most residential buildings have an hourly air exchange rate in the range of 0.25 to 1.0, causing air that enters the building before indoor air sampling to remain in the building for a long time (for example, see Section D.10, ITRC 2007a). Recommended lag times may warrant adjusting for nonresidential buildings.

6.4.3 Sub-slab Soil Gas Sampling

Sub-slab soil gas samples can provide useful data for characterizing the levels of hazardous, vapor-forming chemicals that can enter a building via soil gas intrusion. When combined with other soil gas data, sub-slab soil gas data can be used to assess whether the subsurface vapor migration pathway is complete (i.e., subsurface vapor migration is capable of transporting hazardous vapors from the source to building; see Section 6.3.2). When combined with an appropriate attenuation factor (e.g., a conservative generic value – see Section 6.5.2), sub-slab soil gas data can be used to estimate a potential upper-bound indoor air concentration that may arise from vapor intrusion. In this way, sub-slab data can be used to assess the potential for the vapor intrusion pathway to pose a health concern.[62]

Field experience indicates there may be substantial spatial variability in sub-slab soil gas concentrations even over an average-sized footprint of a residential building. Site planning and data review teams should, therefore, consider collecting more than one sample per building when sub-slab soil gas sampling is conducted. Three sub-slab samples have been collected in a number of EPA investigations of a typical size residential building or commercial building less than 1,500 square feet in area. Additional situations that should trigger discussions about the number of sample locations per building include: (1) very large or small homes or buildings;[63] (2) buildings with more than one foundation floor type;[64] (3) subsurface structures or conditions that might facilitate or mitigate vapor intrusion; and 4) multi-use buildings with distinct segmented areas that differ significantly by occupying population or exposure frequency. In addition, multi-point sub-slab samples should be considered to support data interpretation and resolve uncertainties that may arise when:

- There are fewer surrounding buildings that are being sampled (that could have helped the understanding of typical sub-slab values and variability).[65]

- The indoor and sub-slab concentrations for a specific building(s) are out of line with expectations based on data from neighboring homes and other information.

[62] The sub-slab soil gas concentration provides only half of the information for estimating vapor flux into a building. The other information needed is the soil gas flow rate (Q_{soil}), which is embodied in the attenuation factor. The soil gas flow rate can also be explicitly calculated using a model.

[63] For larger structures, a statistician may assist in identifying the number and placement of sampling ports to meet the desired DQOs.

[64] In basements with a partial slab, but one large enough to allow vapors to accumulate (for example, if the slab covers more than 50 percent of the building footprint), EPA generally recommends that one sub-slab port be installed on the slab portion and an indoor air sample be collected directly over the dirt portion.

[65] In these cases, multiple ports should be installed in a specific percentage (e.g., more than 10 percent) of the buildings sampled to provide a check for variability in the study area.

EPA generally recommends that sub-slab sampling include centrally located sub-slab samples in buildings identified for testing when the subsurface vapor source is laterally extensive relative to the building footprint (e.g., a broad plume of contaminated groundwater). Based on work conducted in New York as of the spring of 2010, it appears that the sub-slab concentrations beneath the central area of a home are usually (75 percent of the time) higher than (or as high as) the concentrations closer to the perimeter of the home.[66] Therefore, EPA recommends that site teams consider internal building partitions, HVAC layout, contaminant distribution, utility conduits, and preferential pathways in selecting any additional locations for collecting sub-slab samples.

Several rounds of sampling are generally recommended to develop an understanding of temporal variability of sub-slab soil gas concentrations, particularly when these data are used with the recommended attenuation factor (see Section 6.5.2) to estimate a potential upper-bound indoor air concentration that may arise from vapor intrusion.

If a site team decides to proceed with sub-slab sampling, EPA recommends that leak-testing be performed to ensure the hole is properly sealed, for example, through the use of a helium tracer gas shroud. Because installing soil gas probes can disturb subsurface conditions, EPA recommends that the site team allow some time after the sampling probe has been installed for the subsurface to return to equilibrium conditions. An EPA study of the time needed for the subsurface conditions to come back to equilibrium (equilibration rate) after they have been disturbed by installation of the soil gas probes found that an equilibration time of two hours generally was sufficient because most sub-slab material consists of sand or a sand-gravel mixture—even for buildings built directly on clay (Section 5.0, EPA 2006b).

There also may be special considerations for sub-slab soil gas samples because of either a unique construction (for example, pretension concrete slab) or environmental situation. Key considerations that may be useful to evaluate include, but are not limited to:

- The location of cables in post-tensioned concrete should be identified (usually using ground-penetrating radar) before sub-slab sampling, as drilling through a cable poses a significant health and safety concern and may damage the slab.
- Sub-slab samples should be avoided in areas where groundwater might intersect the slab.
- Underground utilities and structures (for example, electric, gas, water, or sewer lines) should be located and avoided to prevent damage to the lines; however, samples should be collected in close proximity to these potential preferential vapor pathways.
- The primary entry points for vapors in basements might be through the sidewalls rather than from below the floor slab, so the site team might need to augment sub-slab samples with samples through the basement walls.

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[66] This field observation is supported by modeling results for idealized scenarios, which show greater sub-slab soil gas concentrations near foundation centers in under-pressurized residential buildings when the vapor source is laterally extensive relative to the building footprint (EPA 2012b).

Evaluate and Develop Analyte Lists. To characterize potential concentrations entering a building via soil gas, EPA generally recommends that chemical analyses for sub-slab soil gas samples be limited to those vapor-forming chemicals known (based upon subsurface testing) or suspected (based upon site history) to be present in the subsurface environment. Requesting an extensive list of analytes that are not related to subsurface contamination, as discussed previously, may unnecessarily complicate risk communication if indoor air testing reveals volatile chemicals unrelated to vapor intrusion.

Collect Complementary Data While Indoors. When sub-slab soil gas samples are collected, EPA recommends that the following complementary information be gathered by observation or interviews:

- Physical conditions and characteristics that are pertinent to assessing the building's susceptibility to soil gas entry, if any (e.g., potential conduits, such as cracks or floor drains; presence of structures, such as utility pits and elevators; basements or crawl spaces). Such information may help interpret spatial differences in sub-slab or indoor air concentrations within a building.

- Areas with significant over- or under-pressurization relative to the outdoors. Such information may assist in interpreting spatial differences in sub-slab or indoor air concentrations within a building.

- Where outdoor air is mechanically brought into the building by the HVAC system and building(s) interiors are over-pressurized, it may be helpful to also collect ambient air samples to support interpretations of the sub-slab sampling results. If the predominant vapor-forming substances and their respective concentrations in sub-slab soil gas and outdoor air samples are similar, then ambient air may be influencing sub-slab soil gas conditions.

When any type of soil gas sample is collected, EPA generally recommends that relevant meteorological data, such as wind speed, snow or ice cover, significant recent precipitation, and changes in barometric pressure, be recorded. Measurement of pressure differences between the subsurface and the building foundation can also provide valuable information to aid in the interpretation of the sub-slab data.

A potential shortcoming of sub-slab soil gas testing is that gaining access may be difficult (or, in some cases, infeasible). This difficulty can often be overcome by implementing a program of community outreach and engagement that fosters trust and good relationships (see Section 10.0).

When access is granted for indoor sampling, EPA generally recommends collecting sub-slab and indoor air samples contemporaneously using similar sampling and analysis methods and sampling durations to allow for data comparison. The sub-slab sampling ports can be installed after the indoor air sample is deployed and collected (8 - 24 hours later) to avoid biasing the indoor air concentrations with potentially higher sub-slab gas infiltration rates during port installation. Alternatively, the sub-slab ports may be installed prior to indoor air sampling and sampled concurrently with the indoor air samples, provided sufficient time is allowed for the indoor air concentrations to return to "normal" after installation of the sub-slab port.[67]

6.4.4 Soil Gas Sampling

Data obtained from a soil gas survey can be used to identify, locate, and characterize subsurface vapor sources (see Section 6.3.1) and characterize subsurface vapor migration pathways (see Section 6.3.2). Soil gas survey data can also be useful in supporting the design of soil vapor extraction systems and other subsurface remediation systems and the performance assessment of these systems. For these purposes, EPA recommends that soil gas survey data be supported by site-specific geologic information (i.e., site geology and subsurface lithology).

Typically, grab (rather than time-integrated) samples are collected when sampling soil gas. EPA recommends that the site team allow some time after the sampler has been installed for the subsurface to return to equilibrium conditions because installing temporary or permanent soil gas probes can disturb subsurface conditions. The equilibration time may depend on the type of drilling techniques used to install the soil gas probes, with more time needed for auger drilling compared with hand drilling. For example, the California Environmental Protection Agency recommends an equilibration time of two hours for temporary driven probes and 48 hours for probes installed using augered borings (CalEPA 2012).

Wind direction, precipitation information, and other site-specific information that can influence soil gas concentration patterns should be documented at the time of sampling.

EPA recommends that soil gas samples be taken as close to the areas of interest as possible and preferably from directly beneath the building structure. As vapors are likely to migrate upward through the coarsest or driest material in the vadose zone, EPA also recommends that soil gas samples be collected from these materials.

Using vertical boring or drilling techniques, it is generally practical to collect soil gas samples only in locations exterior to a building's footprint ("exterior" soil gas samples). Modeling results for idealized scenarios show that, in homogeneous soil, soil vapor concentrations tend to be greater beneath the building than at the same depth in adjacent open areas when the vapor source is laterally extensive relative to the building footprint (e.g., broad plume of contaminated groundwater) (EPA 2012b). Given these predictions and supporting field evidence (EPA 2012a, see Figure 6), individual exterior soil gas samples cannot generally be expected to accurately estimate sub-slab or indoor air concentrations. This potential limitation may be particularly valid for shallow soil gas samples collected exterior to a building footprint.

Deeper soil gas samples collected in the vadose zone immediately above the source of contamination (i.e., "near-source" soil gas samples) are more likely to be representative of what

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[67] EPA generally recommends delaying indoor air testing for at least 24 to 72 hours based on an approximate air exchange rate of 0.25 to 1.0 per hour. Note that the effects of any 'spike' in indoor air concentration may linger depending on source strength, relative humidity inside the building, and the extent to which the contaminants have been absorbed by carpets and other fabrics or "sinks."

may be in contact with the building's sub-slab. Several rounds of sampling are generally recommended to develop an understanding of temporal variability of "near-source" soil gas concentrations, particularly when these data are used with the recommended attenuation factor (see Section 6.5.2) to estimate a potential upper-bound indoor air concentration that may arise from vapor intrusion.

6.4.5 Groundwater Sampling

Groundwater sampling and analysis also feature prominently in many vapor intrusion investigations, for example, to help characterize plumes that can serve as vapor sources. Groundwater sampling methods are not discussed here because practitioners typically are relatively experienced and trained to collect samples that meet site-specific data quality needs (see, for example, EPA-ERT 2001a). However, Section 6.3.1 provides a few recommended guidelines for groundwater sampling that are pertinent to vapor intrusion. One key consideration in sampling groundwater for vapor intrusion investigations is focusing on characterizing water table concentrations. EPA recommends that groundwater samples be taken from wells screened (preferably over short intervals) across the top of the water table. Vapor-forming contaminants in the uppermost portions of an aquifer, including the capillary fringe, are likely to volatilize into the vadose zone with the potential to migrate into indoor air spaces. Because fluctuations in water table elevation can lead to elevated source vapor concentrations, EPA also recommends that a soil gas survey be considered in such areas.

Groundwater data obtained in accordance with these recommendations can be compared to the groundwater VISLs (see Section 6.5.3).[68] When combined with an appropriate attenuation factor (see Section 6.5.2), groundwater data can be used to estimate a potential upper-bound indoor air concentration that may arise from vapor intrusion. In these ways, groundwater data can be used to assess the potential for vapor intrusion from groundwater sources to pose a health concern.

6.4.6 Planning for Building and Property Access

Vapor intrusion investigations generally entail gaining legal access to buildings and properties to conduct sampling. Public outreach and communication for this purpose should generally be conducted in accordance with the site-specific community involvement plan (See Section 10.1).

Obtaining and scheduling access to a property and building can become difficult, whether the structure is a commercial or institutional building or a private residence. This potential difficulty can often be overcome by implementing a program of community outreach and engagement that fosters trust and good relationships.

To address these practical and logistical concerns during the planning stage, EPA recommends that an access agreement be executed between the property owner, any tenants, and the

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[68] If available groundwater data do not meet these criteria, the site data review team should judge whether they are nevertheless representative of potential vapor source concentrations emanating from groundwater.

investigating entity. Section 10.3 provides additional guidance for addressing building and property access for sampling.

6.5 Overview of Risk-Based Screening

Risk screening for vapor intrusion generally is performed using site-specific data collected via appropriate methods, as described in Section 6.4. In some cases, pre-existing data identified during a preliminary analysis can be deemed reliable and adequate for use in risk-based screening (see Section 5.5).

The primary objective of risk-based screening is to identify sites or buildings likely to pose a health concern through the vapor intrusion pathway. Risk-based screening can also support a preliminary health risk analysis of individual building data (e.g., indoor air concentrations), including identification of buildings that may warrant prompt response action.

Along with other lines of evidence, risk-based screening can help focus a subsequent site-specific investigation (e.g., results of source strength screening can help identify and prioritize buildings for indoor testing) or provide support for considering building mitigation and other risk management options (see Sections 8.0 and 9.0).

6.5.1 Scope and Basis for Health-based, Vapor Intrusion Screening Levels

EPA developed VISLs for human health protection that are generally recommended, medium-specific, risk-based screening-level concentrations intended for use in identifying areas or buildings that may warrant further investigation of the vapor intrusion pathway. These VISLs are based on:

- Current toxicity values selected in accordance with OSWER's hierarchy of sources for toxicity values (EPA 2003).
- Physical-chemical parameters for vapor-forming chemicals.
- EPA-recommended risk assessment approaches.

The VISLs for human health protection include indoor air screening levels for long-term exposures, which consider the potential for cancer and noncancer effects. The VISLs for human health protection also include subsurface screening levels for comparison to sub-slab soil gas, "near-source" soil gas, and groundwater sampling results. These screening levels are derived from the indoor air screening levels for long-term exposures using medium-specific, generic attenuation factors described further in Section 6.5.2 and Appendix B. The VISL user's guide provides additional information about derivation of the indoor air and subsurface screening levels (EPA 2012c).

The medium-specific VISLs for human health protection are intended to be compared to:

- Building-specific data, such as results from sub-slab soil gas samples, crawl space samples, or indoor air samples; or

- Site- or building-specific data that characterize subsurface vapor sources (e.g., groundwater samples, “near-source” soil gas concentrations)

to determine if there is a potential for the vapor intrusion pathway to pose a health concern to building occupants. The VISLs for human health protection are not intended, however, to be used as final cleanup levels for site remediation.

EPA intends to update the health-based VISLs periodically to incorporate changes in toxicity values, if any, in accordance with OSWER’s hierarchy of sources for toxicity values (EPA 2003). If and when warranted, physical-chemical parameters may also be updated periodically. In part to facilitate these updates, EPA has developed a VISL Calculator, which will be updated periodically (see Section 1.4.1).

The medium-specific VISLs for health protection are developed considering a generic conceptual model for vapor intrusion consisting of:

- A source of vapors underneath the building(s) either in the vadose zone or in the uppermost, continuous zone of groundwater.
- Vapor migration via diffusion upwards through unsaturated soils from these sources toward the ground surface and overlying buildings.
- Buildings with poured concrete foundations (e.g., basement or slab-on-grade foundations) that are susceptible to soil gas entry.

A critical assumption for this generic model is that site-specific subsurface characteristics will tend to reduce or attenuate vapor concentrations as vapors migrate upward from the source and into overlying structures. Specific factors that may result in relatively unattenuated or enhanced transport of vapors into a building include the following:

- Significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations.
- Very shallow groundwater sources (e.g., depths to water less than five feet below foundation level) (see, for example, EPA (2012a), Section 5.2).
- Significant preferential pathways for subsurface vapor migration whether naturally-occurring (e.g., fractured bedrock) or anthropogenic.

These specific factors are likely to render inappropriate the use of the recommended attenuation factors and the sub-slab, groundwater, and soil gas VISLs for health protection.

Vapor source types that typically make the use of the recommended attenuation factors and health-based VISLs for groundwater and soil gas inappropriate include:

- Those originating in landfills where methane is generated in sufficient quantities to induce advective transport in the vadose zone.

- Those originating in commercial or industrial settings where vapor-forming chemicals can be released within an enclosed space and the density of the chemicals' vapor may result in significant advective transport of the vapors downward through cracks and openings in floors and into the vadose zone.

- Leaking vapors from gas transmission lines.

In each case, the diffusive transport of vapors may be overridden by advective transport, and the vapors may be transported in the vadose zone several hundred feet from the source of contamination with little attenuation in concentration.

In general, EPA recommends that the user consider whether the assumptions underlying the generic conceptual model are applicable at a given site. If they are not applicable, then EPA recommends that the user not rely upon the medium-specific VISLs as a line of evidence for characterizing the vapor intrusion pathway. Where the assumptions regarding the subsurface attenuation factors do not or may not apply, EPA recommends collecting indoor air samples.

It should be emphasized that these VISLs are not response action levels or cleanup standards**.** Instead, they are intended to be used to streamline the evaluation of sites and buildings by helping the data review team identify areas, buildings, and/or chemicals of potential concern that can be eliminated from further assessment at sites with subsurface sources of vapor-forming chemicals. Comparison of sample concentrations to the VISLs is only one factor used in determining the need for a response action at a site. As discussed further in Section 6.5.3, an individual subsurface sampling result that exceeds the respective, long-term screening level does not establish that vapor intrusion will pose an unacceptable health risk to building occupants. Conversely, these generic, single-chemical VISLs do not account for the cumulative effect of all vapor-forming chemicals that may be present. Thus, if multiple chemicals that have a common, non-cancer toxic effect are present, a significant health threat may exist at a specific building or site even if none of the individual substances exceeds its VISL.

6.5.2 Recommended Attenuation Factors for Health-based Screening

Vapor attenuation refers to the reduction in volatile chemical concentrations that occurs during vapor migration in the subsurface, coupled with the dilution that can occur when the vapors enter a building and mix with indoor air (Johnson and Ettinger 1991). The aggregate effect of these physical and chemical attenuation mechanisms can be quantified through the use of a vapor intrusion attenuation factor, which is defined as the ratio of the indoor air concentration arising from vapor intrusion to the subsurface vapor concentration at the source or a depth of interest in the vapor migration pathway (EPA 2012a).[69]

EPA compiled a database of empirical attenuation factors for chlorinated VOCs and residential buildings through review of data from 913 buildings at 41 sites with indoor air concentrations

[69] As defined here, the vapor attenuation factor is an inverse measurement of the overall dilution that occurs as vapors migrate from a subsurface source into a building; i.e., lower attenuation factor values indicate lower vapor intrusion impacts and greater dilution; higher values indicate greater vapor intrusion impacts and less dilution (EPA 2012a, b). Johnson and Ettinger (1991) utilized the symbol α for the vapor intrusion attenuation factor.

paired with sub-slab soil gas, groundwater, exterior soil gas, or crawl space concentrations (EPA 2012a). After removing data that do not meet quality criteria and data likely to be influenced by background sources, the distributions of the remaining attenuation factors were analyzed graphically and statistically.[70] Based upon these analyses, the attenuation factors in Table 6-1 are recommended by EPA to derive the VISLs for health protection.

TABLE 6 1
RECOMMENDED VAPOR ATTENUATION FACTORS FOR RISK BASED SCREENING OF THE VAPOR INTRUSION PATHWAY[71]

Sampling Medium	Medium-specific Attenuation Factor for Residential Buildings
Groundwater, generic value, except for shallow water tables (less than five feet below foundation) or presence of preferential pathways in vadose zone soils	1E-03 (0.001)
Groundwater, specific value for fine-grained vadose zone soils, when laterally extensive layers are present[72]	5E-04 (0.0005)
Sub-slab soil gas, generic value	3E-02 (0.03)
"Near-source" exterior soil gas, generic value except for sources in the vadose zone (less than five feet below foundation) or presence of preferential pathways in vadose zone soils	3E-02 (0.03)
Crawl space air, generic value	1E-00 (1.0)

With the exception of the "near-source" exterior soil gas attenuation factor, the recommended values for residential buildings are the estimated 95th percentile values, rounded to one significant figure. The rationale for these recommendations and related analyses is provided in Appendix B. These recommended values are proposed to apply to all vapor-forming chemicals

[70] A summary of the resulting distributions is provided in Appendix B of this document.

[71] Use of these attenuation factors for estimating indoor air concentrations is contingent upon site conditions fitting the generic model of vapor intrusion described in Section 6.5.1 and subsurface conditions being characterized in accordance with the recommendations in Sections 6.3 and 6.4.

[72] The Draft VI Guidance allows for the modification of VISLs for groundwater by incorporating a lower attenuation factor, based upon "some site-specific inputs", which estimates a greater reduction in vapor concentrations in the vadose zone than the generic value (EPA 2002c, 2010b). In the Draft VI Guidance, graphs were provided from which such "semi-site-specific" attenuation factors could be selected and justified based upon site-specific soil type and depth to the water table. Based upon analysis of EPA's expanded database, a single groundwater attenuation factor is provided in this Final VI Guidance for fine-grained soils.

for use in estimating potential upper-bound concentrations in indoor air that may arise from vapor intrusion. When evaluating chemicals that are biodegradable in the vadose zone, the user should recognize that these recommended groundwater and "near-source" soil gas attenuation factors do not include the effects of biodegradation.[73] Because biodegradation is not expected to occur indoors (i.e., in indoor air in the absence of an air treatment system), the sub-slab soil gas and crawl space attenuation factors are expected to apply equally to vapor-forming chemicals that biodegrade in the vadose zone and those that do not.

As with the medium-specific VISLs, the user should consider whether there are site- or building-specific factors that may result in unattenuated or enhanced transport of vapors toward and into a building, such as the presence of preferential migration pathways as described in Section 5.5. The presence of such factors is likely to render inappropriate the use of any of these generic attenuation factors.

The VISL Calculator (http://www.epa.gov/oswer/vaporintrusion/guidance.html) also facilitates calculation of groundwater screening levels based on the recommended attenuation factor for fine-grained soil. Any use and application of this semi-site-specific groundwater attenuation factor should be supported by site-specific geologic information (i.e., site geology and subsurface lithology). Significant characterization of the vadose zone may be needed to demonstrate that fine-grained layers are laterally extensive over distances that are large compared to the size of the building(s) or the extent of vapor contamination at a specific site, which is the recommended support for using the semi-site-specific attenuation factor for fine-grained soil.[74] For purposes of applying the groundwater attenuation factors, the depth to groundwater should be estimated relative to the bottom of the building foundation and should be based upon the seasonal high groundwater table.

6.5.3 Comparing Sample Concentrations to Health-based Screening Levels

When evaluating environmental sampling results to assess the vapor intrusion pathway, it is important to first determine that the samples were collected appropriately. Section 6.4 provides guidance about recommended sampling locations and procedures for vapor intrusion investigations. In addition, EPA recommends collecting and evaluating appropriate site-specific information to demonstrate that the property fulfills the conditions and assumptions of the generic conceptual model underlying the VISLs, as described in Section 6.5.1.

After verifying that the CSM justifies the use of the VISLs, the individual sample concentrations may be compared to the appropriate medium-specific screening levels. In order to select the appropriate target media concentrations for comparison, it generally is important to identify

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[73] Appropriate data can be collected and evaluated, as described in Section 6.3.2, to characterize and document the occurrence of biodegradation in the vadose zone and its effects in attenuating vapor concentrations of biodegradable vapor-forming chemicals.

[74] The general soil type assigned to paired vapor intrusion data in the EPA's database "generally represents the coarsest soil described in the vadose zone near the sample location" unless "sufficient stratigraphic information was available to indicate finer sediments are laterally continuous" (EPA 2012a). EPA recommends that similar criteria be applied to justifying the use of the semi-site-specific attenuation factor for groundwater (or selection of soil-related parameters for modeling (see Section 6.6). For these purposes, soil classified as clay, silty clay, silty clay loam, or silt in accordance with the U.S. Soil Conservation Service classification system can be considered to be "fine-grained."

whether a source of vapors for a building or a developed area occurs in the unsaturated zone, which is an important aspect of the CSM. This allows the site data to be segregated into two categories:

1) Data representing areas where contaminated groundwater is the only source of contaminant vapors.

   In this first case, groundwater VISLs are generally appropriate to use to evaluate groundwater concentrations obtained in accordance with the recommendations in Sections 6.3.1 and 6.4.5. To demonstrate that groundwater poses negligible risk of vapor intrusion on an area-wide basis, it may be appropriate to compare sampling results for the most greatly impacted well within the area of interest and show that these results are less than the groundwater VISLs. Under these circumstances, EPA recommends that the plume be shown to be stable or shrinking (i.e., is not migrating or rising in concentration, including hazardous byproducts of any biodegradation) to establish that the potential for vapor intrusion to pose a health concern will not increase in the future.

   "Near-source" soil gas data (i.e., soil gas samples collected immediately above the water table) could be compared to the soil gas VISLs to obtain a corroborating line of evidence.

2) Data representing areas where the underlying vadose zone soil contains a source of vapors (e.g., residual NAPL).

   In this second case, EPA recommends that only soil gas VISLs be used and compared to results from "near-source" soil gas samples collected near the vapor source zone. In this situation, the groundwater VISLs (and vapor attenuation factors for groundwater) are not recommended to estimate potential upper-bound indoor air concentrations, because they have been derived assuming no other vapor sources exist between the water table and the building foundation.

In both cases, because of the complexity of the vapor intrusion pathway, EPA recommends that professional judgment be used when applying the VISLs.

Generally, if all sample concentrations for a given building or area are less than the respective medium-specific screening level, then vapor intrusion is less likely to pose an unacceptable health risk to building occupants. On the other hand, when individual sample concentrations exceed the respective screening level, additional assessments may be warranted. So, for example, if a groundwater or "near-source" soil gas concentration exceeds the respective screening level, then sub-slab soil gas testing and indoor air testing may be warranted.

However, we would note that any individual subsurface sampling result that exceeds the respective, long-term screening level does <u>not</u> establish that vapor intrusion will pose an unacceptable health risk to building occupants. For one, the subsurface screening levels are expected to be conservative (i.e., are likely to over-estimate the contribution to indoor air levels arising from vapor intrusion) for many buildings due to the use of a high-end attenuation factor (see Section 6.5.2). In many cases, indoor air concentrations arising from vapor intrusion would be expected to be lower than those estimated using the recommended generic attenuation factors. For carcinogens, the screening levels are set using a one-per-million lifetime cancer risk (i.e., 10^{-6}). Finally, sampling results can be expected to be variable spatially and temporally and these screening levels assume a long period of exposure at the stated concentration.

Owing to the temporal variability in building-specific data and the potential temporal and spatial variability in subsurface vapor concentrations, EPA generally recommends multiple samples be collected (see Section 6.4) and compared to the respective medium-specific screening level. In addition, the results of risk-based screening are generally most useful when they can be evaluated for indoor air and subsurface sources concurrently and in the context of the CSM. EPA, therefore, generally recommends that multiple lines of evidence be developed and their results weighed together when evaluating and making risk-informed decisions pertaining to vapor intrusion. EPA generally recommends that concordance among the multiple lines of evidence be obtained, particularly when considering a determination that the vapor intrusion pathway does not pose an unacceptable health risk. Sections 7.1, 7.2, and 7.3 provide additional information and recommendations about developing and using multiple lines of evidence and risk management decision-making.

6.5.4 Planning for Communication of Sampling Results

The community involvement or public participation plan (See Section 10.1) should address community concerns and preferences for participation regarding sampling results. Generally, EPA recommends that the site planning team provide validated results to property owners and occupants within approximately 30 days of receiving these results. These results can be transmitted in a letter, which should also indicate what future actions, if any, may be necessary. In addition, the site planning team may choose to hold a community meeting to discuss the sampling results in general terms and EPA's plans, if any, for response actions. Section 10.4 provides additional guidance for communicating sampling results.

6.6 General Principles and Recommendations for Modeling

When suitably constructed, documented, and verified, mathematical models can provide an acceptable line of evidence supporting risk management decisions pertaining to vapor intrusion. In certain situations (e.g., for future construction on vacant properties), it is particularly useful to employ mathematical modeling to predict reasonable worse case indoor air concentrations, because indoor air testing is not possible. However, EPA does not recommend modeling as the only line of evidence to screen out a site. Modeling is most appropriately used in conjunction with other lines of evidence. For example, in the brownfield development case (i.e., yet-to-be-constructed building), these additional lines of evidence generally should include, at a minimum, data that characterize potential vapor sources and associated geologic and hydrologic conditions (see Sections 6.3.1 and 6.3.2).

Generally, environmental models transform empirical values of input parameters into predictions of chemical concentrations in environmental media. The model input parameters are equally as important to the results as the mathematical components of the model (i.e., governing equations and solution algorithms). As a consequence, the results critically depend on the choices for the inputs.

Historically, to assure confidence in model predictions, they have been compared to measured values. When measured and predicted values do not reasonably match, model input parameters are adjusted through calibration. For example, calibration is commonly used in groundwater flow modeling, in which model-predicted groundwater levels are matched to measured groundwater levels for a baseline condition to gain insight into hydrogeologic properties. The calibrated input parameters must reasonably represent the underlying phenomena and the characteristics of the model must reasonably match the field situation. Calibration of models is known to be non-unique, so that different sets of parameters can be used to fit the same observed data. This means that calibration does not produce a theoretically correct set of parameters. Because various values of input parameters could be used in the calibrated model, there will always be uncertainty as to the actual values.

Three approaches exist for applying mathematical models in these circumstances:

1) Calibrating the model to the measured indoor air concentration (and, possibly, the sub-slab soil gas concentration) considered to be representative of vapor intrusion (i.e., background sources have been identified and removed prior to sampling and data evaluation indicates that the concentration is reasonably attributable to vapor intrusion). Calibration entails adjusting the input parameters within plausible and realistic ranges so that the predicted indoor air concentrations (or sub-slab soil gas concentrations) are similar to the measured concentrations. The adjusted input parameters can then be compared to site-specific conditions to verify that the CSM is sound.

2) Conducting an uncertainty analysis (perhaps using an automated uncertainty analysis (see http://www.epa.gov/athens/learn2model/part-two/onsite/uncertainty-vi.html as only one example)) to understand where, within the probability distribution of results, model results with pre-selected default parameters lie. This approach may be particularly useful where indoor air concentrations have not been measured or non-site-specific inputs have been used.

3) Using a bounding case analysis, where parameters are chosen to represent conditions that give a high-impact ("reasonable worse") case. This approach may be particularly useful where the predicted "worse case" indoor air concentrations can be shown to pose acceptable health risks. The range of predicted indoor air concentrations can be established if the analysis also includes a low-impact ("best") case.

Unless site-specific parameter values are obtained for input parameters and the model is calibrated to field data, use of default input parameter values will generate model results that lie at an unknown point within an uncertainty band of the model outcomes. Because the combined effect of parameter uncertainty is large, a one- or two-order of magnitude error might be made unknowingly. To reduce these errors, sub-slab vapor sampling could be used to characterize the vapor profile beneath a building. Model results (i.e., predicted sub-slab soil gas concentrations) that match that profile would have increased confidence. Alternately, using bounding estimates of parameter values could provide a conservative model result that would be expected to represent the reasonable worse case of potential exposure.

Three examples follow where differing model applications would be useful:

1) Verify General Magnitude. Modeling using site-specific inputs can be useful for verifying the general magnitude of measured indoor air sample concentrations, which may allow risk managers to reach supportable conclusions not to conduct additional indoor testing. In this situation, the model should be calibrated to indoor air measurements and the plausibility of the calibrated input parameters evaluated. If the calibrated model input parameters are plausible, then they can be considered an additional line of evidence supporting risk management decisions.

2) Explore Range of Outcomes through Uncertainty Analysis. In certain situations, indoor air testing is not possible (e.g., for future construction on vacant properties) or feasible. Here the range of possible outcomes could be explored with the model through an uncertainty analysis. For example, model input parameters, including building and vadose zone soil properties, could be varied within plausible ranges to determine the parameters to which the model is most sensitive to guide field investigations. Uncertainty analyses can also be used to ascertain whether the vapor source concentrations are such that indoor air samples should not be expected to contain detectable levels of vapor-forming chemicals present in the subsurface.

3) Generate Bounding Estimates. If the range of parameter values is known with confidence for the site, then parameters can be chosen to represent the bounding case of maximum plausible vapor intrusion (e.g., worse case).

In each of these examples, model parameters might vary in space and time because of subsurface heterogeneity, transient hydrologic conditions, or variation in building operation. Thus, there is a need for characterizing spatial and temporal variability.

Models provide opportunities to predict conditions that cannot be observed directly, but the reliability of the results need to be questioned, especially when limited site-specific data are available, and the model is not calibrated to observed indoor air concentrations. Use of a generic, conservative attenuation factor (see Section 6.5.2) to predict potential, reasonable worse case indoor air concentrations implicitly represents use of a model, even when the attenuation factor is selected from an empirical data set. Whether the model is implicit (e.g., generic, conservative attenuation factor) or explicit (e.g., mathematical model in screening mode), both analytic approaches make the assumption that site-specific attenuation is likely to be greater and the indoor air concentration(s) is (are) likely to be lower than predicted value(s).

The use of extreme and non-representative assumptions or parameter values is the most common weakness of environmental modeling. Mathematical modeling typically yields more reliable results when used with high-quality, site-specific data inputs (that is, representative groundwater or soil gas concentrations, depth to groundwater, air exchange rate, building mixing height, and soil type, for example) and is calibrated to the observed data; in these cases, the site-specific data inputs and CSM provide additional lines of evidence supporting the use of modeling as a line of evidence.

EPA has developed and refined a spreadsheet program that can be used to estimate indoor air concentrations and associated health risks arising from subsurface vapor intrusion into buildings. The models in this program are based on the analytical solutions of Johnson and Ettinger (1991) for contaminant partitioning and subsurface vapor transport into buildings. This model is well known, was used as an example in the American Society for Testing and Materials (ASTM) risk-based corrective action guide for petroleum hydrocarbons (ASTM 1995), and is recommended or supported by several states when estimating subsurface soil and groundwater concentrations protective of indoor inhalation. The program can be used for any of the above modeling approaches: calibrated modeling, uncertainty analysis, or bounding case analysis. This model does not, however, account for biodegradation, so the results are very conservative for petroleum hydrocarbons and other aerobically-degraded chemicals. The program, additional information, and an associated user's guide (EPA 2013e) are available at OSWER's website devoted to vapor intrusion.

Whenever modeling is used to make predictions pertaining to vapor intrusion, EPA recommends that the site planning and data team:

- Identify the underlying mathematical model and include appropriate references to document that it has been peer-reviewed.
- Verify that the selected model fits the CSM and is appropriate for the chosen purpose.
- Document all inputs and outputs in a readily recognizable and understandable format.
- Identify the critical parameters and conduct a sensitivity analysis for the most critical parameters.
- Determine and document the appropriate modeling approach (e.g., calibration, uncertainty analysis, bounding case analysis).
- Perform new individual measurements (i.e., field sampling) to confirm one or more results of the modeling.

A critical assumption underlying almost all models of vapor intrusion is that site-specific subsurface characteristics will tend to reduce or attenuate vapor concentrations as vapors migrate upward from the source and into overlying structures. Mathematical modeling of vapor intrusion is, therefore, not generally recommended for sites and buildings where unattenuated or enhanced transport of vapors toward and into a building is reasonably expected. Section 6.5.1 identifies several factors that may result in unattenuated or enhanced transport of vapors toward and into a building.

7.0 RISK ASSESSMENT AND MANAGEMENT FRAMEWORK

This section provides general recommendations about risk-informed decision-making pertaining to vapor intrusion. The risk-management guidance described herein presumes that a sound CSM has been developed (see Sections 5.4 and 6.2), which is supported by multiple lines of evidence, and that subsurface vapor sources have been characterized (see Section 6.3.1) sufficiently to support the risk management decisions for the site. EPA also notes that temporal and spatial variability of sampling data can span at least an order of magnitude and often more.

Site-specific decisions potentially supported by the guidance described in this section include:

- Whether to install engineered exposure controls to prevent or reduce the impacts of vapor intrusion in specific buildings.

- Whether to remediate subsurface vapor sources for the site to reduce risks posed by vapor intrusion.

- Whether the vapor intrusion pathway is incomplete and there is no potential for human exposure under current or future conditions.

- Whether to collect additional information as part of the detailed vapor intrusion investigation or monitor indoor air as part of an overall vapor intrusion remedy.

As conditions warrant and resources allow, EPA generally recommends that officials responsible for overseeing cleanups pursuant to RCRA and CERCLA ensure that past decisions pertaining to vapor intrusion continue to be supported by current conditions (EPA 2002b).

Finally, EPA encourages systematic approaches to decision-making, which can foster scientific rigor, consistency, and transparency.

7.1 Collect and Weigh Site-specific Lines of Evidence

Current practice suggests that the vapor intrusion pathway generally should be assessed using multiple lines of evidence. As discussed in Sections 5.1, 5.5, 5.6.2, 6.3, 6.4, and 6.5, lines of evidence to support development of the CSM and evaluate the vapor intrusion pathway may include, but are not limited to:

<u>Subsurface Vapor Sources</u>

- Site history and source of the contaminants to demonstrate that vapor-forming chemicals have been or may have been released to the underlying and surrounding subsurface environment and identify the type of vapor source (e.g., vapor-forming chemicals dissolved in groundwater or present in a NAPL).

- Groundwater data (generally recommended from more than one sampling event), as appropriate, to confirm the presence of a water-table aquifer as a source of vapors, if applicable, and establish its chemical and hydrogeologic characteristics.

- Soil gas data, bulk soil sampling data, and/or NAPL sampling data to confirm the presence of contamination in the vadose zone as a source of vapors, if applicable, and establish its chemical and physical characteristics.

- Comparison of groundwater and soil gas concentrations to VISLs to evaluate source strength and potential for a health concern if the vapor intrusion pathway is complete.

Vapor Migration and Attenuation in the Vadose Zone

- Soil gas survey data, including some level of vertical and spatial profiling, as appropriate, to confirm soil gas migration and attenuation along anticipated paths in the vadose zone between sources and buildings.

- Data on site geology and hydrology (e.g., soil moisture and porosity) to support the interpretation of soil gas profiles, the characterization of gas permeability, and the identification of anticipated soil gas migration paths in the vadose zone or the identification and characterization of impeded migration.

- Vertical profiles of chemical vapors, electron acceptors for microbial transformations (e.g., oxygen), and biodegradation products (e.g., methane, vinyl chloride) to characterize attenuation due to biochemical processes.

- Utility corridor assessment to identify preferential pathways for subsurface vapor migration between sources and buildings

Building Foundation Assessment, Including Susceptibility to Soil Gas Entry

- Building construction and current conditions, including utility conduits or other preferential pathways of soil gas entry, heating and cooling systems in use, and any segmentation of ventilation and air handling.

- Tracer-release (e.g., sulfur hexafluoride) data to verify openings in building foundations for soil gas entry or assess fresh air exchange within buildings.

- Instrumental (e.g., PID) readings to locate and identify potential openings for soil gas entry into buildings.

- Grab samples of indoor air near openings for soil gas entry into buildings.

- Pressure data to assess the driving force for soil gas entry into building(s) via advection.

Interior Assessment

- Sub-slab (or crawl space) soil gas data (generally recommended from more than one sampling event and in multiple locations) to assess concentrations potentially available for entry with any intruding soil gas.

- Indoor air sampling data (generally recommended from more than one sampling event[75] and for multiple locations in a given building) to assess the presence of subsurface contaminants in indoor air, estimate potential exposure levels to building occupants to support site-specific exposure and risk assessments (see Section 6.7.2), and otherwise diagnose vapor intrusion.

- Results of mathematical modeling that rely upon site-specific inputs.

- Comparative evaluations of indoor air and sub-slab soil gas data, including calculation and comparison of building-specific, empirical attenuation factors (EPA 2012a, Section 3.0) (e.g., to assess their consistency among subsurface contaminants to assist in identifying indoor vapors arising from vapor intrusion).

Indoor and Outdoor Sources of Vapor-forming Chemicals Found in the Subsurface

- Building-specific indoor sources of volatile chemicals.

- Concurrent outdoor air data to assess potential contributions of ambient air to indoor air concentrations.

Additional Supporting Lines

- Results of statistical analyses (e.g., data trends, contaminant ratios) to support data interpretation.

The relative strength of these and other individual lines of evidence will depend on site-specific factors, which should be reflected in the CSM, and the objectives of the investigation. For example:

- When the primary subsurface vapor source is NAPL in the vadose zone, soil gas or bulk soil data would generally be needed to characterize the extent of the vadose zone contamination, as discussed in Section 6.3.1.[76] In this situation, groundwater data would not be necessary for assessing the potential for vapor intrusion to pose an unacceptable

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[75] In certain cases, depending in part on the results (e.g., concentrations exceed risk-based screening levels), indoor air sampling data may be a sufficient basis for supporting decisions to undertake pre-emptive mitigation (see Section 9) in lieu of additional rounds of sampling and analysis or an evaluation of the contribution of background sources to indoor air concentrations.

[76] Because of the large uncertainties associated with measuring concentrations of volatile contaminants introduced during soil sampling, preservation, and chemical analysis, bulk soil (as opposed to soil gas) sampling and analysis is not currently recommended for estimating the potential for vapor intrusion to pose unacceptable health risks in indoor air. In addition, there are uncertainties associated with soil partitioning calculations.

risk to occupants of any building overlying the NAPL zone. When shallow groundwater is the primary subsurface vapor source underneath a building, groundwater sampling data from the uppermost hydrogeologic unit would be an appropriate line of evidence for purposes of assessing the potential for vapor intrusion to pose an unacceptable health risk, unlike the previous example.

- In both of the preceding cases, information about the type of soil *underlying the buildings* would be useful for characterizing the subsurface vapor migration path between the subsurface vapor source and the building. Sub-slab soil gas samples and indoor air samples (if background sources are removed or accounted for), in concert with other lines of evidence, can provide a strong line of evidence regarding the completeness of the vapor intrusion pathway.

- For an industrial building, indoor air testing while the HVAC system is not operating (see Section 6.3.3) could be useful for diagnosing vapor intrusion. On the other hand, single-family detached homes can generally be presumed susceptible to soil gas entry when heating or cooling systems are operating.

7.2 Assess Concordance Among the Lines of Evidence

To the risk manager, the ideal outcome from collecting multiple lines of evidence is a concordant set of site-specific information that unambiguously supports decisions that can be made confidently. Based upon accumulated observations at many buildings and sites, the vapor intrusion site where all available information is in agreement and is unambiguous may be the exception rather than the rule. Some lines of evidence may not be definitive. Indoor air and subsurface concentrations can be greatly variable temporally and spatially. At worse, some individual lines of evidence may be inconsistent with other lines of evidence. In general, when lines of evidence are not concordant and the weight of evidence does not support a confident decision, EPA recommends collecting a new line(s) of evidence (e.g., indoor air data, if only subsurface data have been collected so far), an additional round of sampling data, or appropriately adjusting the CSM to better represent the weight of the available evidence.

For example, a building overlying contaminated shallow groundwater may have high concentrations of vapor-forming chemicals in the sub-slab soil gas samples, but lower concentrations in soil gas samples collected exterior to the building at intermediate depths. In this example, the exterior soil gas data suggest there may not be a connected vapor migration path between the groundwater source and the building that exhibits continuous attenuation along the path. Nevertheless, the data review team may conclude that vapor migration is capable of transporting hazardous vapors from the source to building(s) if the groundwater and sub-slab soil gas samples share common contaminants that are known or suspected to have been released at the site (for example, samples of both groundwater and the sub-slab soil gas contain TCE). In this circumstance, the data review team may wish to consider whether the occurrence of a higher TCE concentration in the sub-slab soil gas than in the exterior soil gas sample(s) can be explained by: (1) a previously unknown or unrecognized utility corridor or other preferential pathway that provides relatively unattenuated vapor transport between the groundwater and the building; (2) a previously unknown or unrecognized source of TCE in the vadose zone; or (3) the possibility that the soil gas samples were not well located for purposes of characterizing subsurface vapor *migration. This example also underscores the importance of developing an adequate CSM (e.g., identify all sources and preferential subsurface pathways) and illustrates why EPA generally recommends that the vapor intrusion pathway not be deemed incomplete based upon any single line of evidence (EPA 2010), such as exterior soil gas in this example.*

When lines of evidence are not concordant and the weight of evidence does not support a confident decision, additional sampling or collecting additional lines of evidence may be appropriate, depending upon the CSM. For example:

- Appropriate site-specific testing (see Section 6.3.5) can be conducted to assess the contribution of background sources of vapor-forming chemicals, including comparisons among chemicals of their relative concentrations in indoor air, outdoor air, and soil gas. Background sources of vapor-forming chemicals may help to explain situations where the indoor air concentration is higher than can be accounted for by the subsurface vapor source or the sub-slab soil gas data.

- Diagnostic testing of indoor air (see Section 6.4.1), building condition assessments or utility surveys, or supplemental hydrogeologic characterization (see Section 6.3.2) can be used to investigate the suspected presence of preferential pathways, such as those described in Section 5.4. Such investigations may help to explain situations where the sub-slab or indoor air concentration appears to reflect unattenuated vapor transport from the subsurface vapor source.

- Building susceptibility to vapor intrusion can be tested (see Section 6.3.3), which may help to explain situations where the indoor air concentration is significantly lower than expected based upon the sub-slab soil gas data.

- Vapor migration in the vadose zone can be further characterized to identify impedances to vapor migration (see Section 6.3.2), appropriate semi-site specific attenuation factors can be considered (see Section 6.5.2), and appropriate modeling can be conducted (see Section 6.6) to investigate site-specific vapor attenuation. Such data and analyses may help to explain situations where the sub-slab soil gas concentration is significantly lower than expected based upon groundwater source or “near-source” soil gas concentrations and the respective medium-specific attenuation factor. In some of these situations, the vapor intrusion pathway may be impeded, or perhaps even incomplete, due to geologic, hydrologic, or microbial characteristics in the vadose zone.

Recognizing the temporal and spatial variability of indoor air and subsurface concentrations and the potentially episodic nature of vapor intrusion at some sites, EPA generally recommends collecting more than one round of sampling in the respective media from more than one location. As a result of evaluating multiple data sets from individual sampling events, the data review team might be faced with considering different recommended response actions for different sampling events. Considerable judgment may be necessary in reconciling such outcomes and supporting decision-making.

In summary, EPA generally recommends the appropriate use and evaluation of a multiple lines of evidence approach for determining whether the vapor intrusion pathway is complete or not, whether any elevated levels of contaminants in indoor air are likely caused by subsurface vapor intrusion versus an indoor source or an ambient (outdoor) air source, whether concentrations of subsurface contaminants in indoor air pose a health concern, and whether interim response measures to mitigate vapor intrusion are warranted.

7.3 Evaluate Whether the Vapor Intrusion Pathway is Complete or Incomplete

Considerable scientific and professional judgment may be needed when weighing lines of evidence to determine whether the vapor intrusion pathway is complete or incomplete. In accordance with the conceptual model of vapor intrusion (see Section 2), the vapor intrusion pathway is deemed likely to be complete for a specific building or collection of buildings when:

- A subsurface source of vapor-forming chemicals is present (see Sections 5.3 and 6.3.1).
- Subsurface vapor migration is capable of transporting hazardous vapors from the source to buildings (see Section 6.3.2).
- Buildings are susceptible to soil gas entry, which may include consideration of conditions when HVAC systems are not operating (see Section 6.3.3).
- Vapor-forming chemicals are present in the indoor environment (which can be confirmed by indoor air sampling and analysis for site-related vapor-forming chemicals that also are found in the subsurface environment (see Sections 6.3.4 and 6.4.1)).

Each of these conditions entails obtaining and weighing multiple lines of evidence. The various lines of evidence should be considered and evaluated together in determining completeness of the vapor intrusion pathway.

The conceptual model described in Section 2 identifies the characteristics of the vadose zone that could render the vapor intrusion pathway incomplete under current and future conditions. These individual characteristics include, but are not limited to:

- Soil layers that impede vapor transport due to geologic or hydrologic conditions (e.g., fine-grained soil, soil with high moisture content) and are laterally extensive over distances that are large compared to the size of the building(s) or the extent of subsurface contamination with vapor-forming chemicals; and
- A biologically active vadose zone that can significantly attenuate vapor concentrations due to biodegradation, in which all appropriate conditions (e.g., nutrients, moisture, and electron acceptors, such as dissolved oxygen in the case of aerobic biodegradation) are readily available over a laterally extensive area.

When present, these characteristics should generally be established by collecting, evaluating, and documenting multiple lines of evidence, as identified in Section 6.3.2. In addition, EPA recommends that any determination that the vapor intrusion pathway is incomplete be supported by site-specific evidence to demonstrate that:

- The nature and extent of vapor-forming chemical contamination in the subsurface has been well characterized. Ideally, where groundwater is the source of vapors, the plume has been shown to be stable or shrinking to establish that the potential for vapor intrusion to pose a health concern will not increase in the future.

- The types of vapor sources and the conditions of the vadose zone and surrounding infrastructure do not present opportunities for unattenuated or enhanced transport of vapors toward and into any building (e.g., via preferential migration pathways), as discussed in Sections 6.2.1 and 6.5.1.

When the vapor intrusion pathway is determined to be incomplete, then vapor intrusion mitigation is not generally warranted under current conditions. EPA recommends that site managers also evaluate whether subsurface vapor sources that remain have the potential to pose unacceptable health risks due to vapor intrusion in the future if site conditions were to change. For example, potentially unpredictable changes in the transitory soil characteristics (e.g., soil moisture) and subsurface vapor concentrations may occur as a result of constructing a new building or supporting infrastructure. Either type of change could result in the potential for unacceptable health risks due to vapor intrusion in the future. Response actions may, therefore, be warranted to protect human health wherever and as long as subsurface vapor sources remain that have the potential to pose unacceptable health risks in the future due to vapor intrusion. These response actions (see Section 7.6) may include institutional controls (see Section 8.6) (e.g., to record the presence of subsurface vapor sources and/or to require a confirmatory vapor intrusion investigation if infrastructure or geologic conditions are modified in the future). In addition, subsurface remediation may be warranted to protect human health or the environment via other exposure pathways (e.g., groundwater discharge to surface water bodies) in accordance with applicable statutes.

7.4 Conduct and Interpret Human Health Risk Assessment

EPA generally recommends that a human health risk assessment be conducted to determine whether the potential human health risks posed to building occupants are within or exceed acceptable levels in accordance with applicable statutes. The risk posed to building occupants by intrusion of a given vapor-forming chemical will depend upon its toxicity, its concentration in indoor air, the amount of time the occupants spend in the building, and other variables (e.g., life stage of population can matter for some chemicals). EPA recommends that risk assessment guidance be used to identify, develop, and combine information about these variables and characterize health risks due to vapor intrusion from subsurface contaminant sources.

For the vapor intrusion pathway, the inhalation route is the primary means of human exposure. Therefore, the health risk assessment uses estimates of indoor air exposure concentrations, exposure duration and frequency for building occupants, and the potential toxicity of the vapor-forming chemicals found in the subsurface (e.g., inhalation unit risk and noncancer reference concentration) to characterize risks of cancer and noncancer effects (EPA 2009c). Generally, exposure concentrations in existing buildings can be estimated using direct measurements of indoor air (see Sections 6.3.4 and 6.4.1). EPA recommends that time-integrated measurements from more than one sampling event generally be used to estimate exposure concentrations appropriate for the exposure (occupancy) scenario being evaluated (e.g., residential versus commercial). The noncancer assessment should consider the potential for adverse health effects from short-duration exposures to elevated exposure concentrations (i.e., acute, short-term, or subchronic exposure durations),[77] as well as longer term exposure (i.e., chronic exposure) conditions. Toxicity values should be selected in accordance with OSWER's hierarchy of sources (EPA 2003).

When a single vapor-forming chemical is present in the subsurface and intrudes as a vapor into occupied building spaces, the noncancer health risk can be characterized by calculating the noncancer hazard quotient (HQ). When multiple vapor-forming chemicals are present in the subsurface and intrude as vapors into occupied building spaces, the HQ estimates for each chemical are aggregated (as a simple sum), based upon the assumption that each chemical acts independently (i.e., there are no synergistic or antagonistic toxicity interactions among the chemicals), after segregating the chemicals by toxic effect to derive separate hazard index (HI) values for each effect.

The carcinogenic risks can be characterized by calculating the excess cancer risk over a lifetime (LCR) and, if multiple vapor-forming chemicals are present, aggregating the LCR estimates for each carcinogen (as a simple sum), based upon the assumption that each chemical acts independently.

Where the aggregated carcinogenic risk to an individual based upon a reasonable maximum exposure condition for both current and future land use is less than one per ten thousand (i.e., 10^{-4} or one hundred per million) and the noncancer HI is less than 1, response action is generally not warranted for vapor intrusion.[78] The upper boundary of the risk range is not a discrete line at 10^{-4}. A specific risk estimate around 10^{-4} may be considered acceptable if justified based on site-specific conditions. A risk manager may also decide that a risk level less than 10^{-4} is unacceptable due to site-specific reasons and that response action is warranted.

Any human health risk assessment should be documented and summarized in any decision document.

7.5 Concentration Levels Indicating Potential Need for Prompt Response Action

In some circumstances, safety and health concerns arise from vapor intrusion, which warrant prompt response action. This Section provides some recommendations for identifying such circumstances.

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[77] The inhalation reference concentration (RfC) (expressed in units of mass concentration in air) is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. "Reference values may also be derived for acute (≤24 hours), short-term (>24 hours, up to 30 days), and subchronic (>30 days, up to approximately 10% of the life span) exposure durations, all of which are derived based on an assumption of continuous exposure throughout the duration specified." See http://www.epa.gov/ncea/iris/help_ques.htm#whatiris

[78] When a single vapor-forming chemical is present in the subsurface and intrudes as a vapor into occupied building spaces, the single-chemical LCR and HQ values are evaluated using the same risk benchmarks as described for multiple chemicals.

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7.5.1 Potential Explosion Hazards

EPA recommends using the chemical-specific LELs to identify potential explosion hazards (e.g., for methane and other petroleum hydrocarbons). Whenever building-specific data (such as results from sub-slab soil gas samples and crawl space samples for any building type or indoor air samples from sheds, pump houses, or other confined or semi-confined spaces) exceed one-tenth (10%) of the LEL for any chemical, a hazard is indicated that generally warrants prompt action.[79,80] EPA recommends evacuation of buildings with potential explosion and fire hazards, along with notification of the local fire department about the threat.

7.5.2 Considering Short-term and Acute Exposures

EPA may identify health-protective concentration levels for vapor-forming chemicals based upon potential noncancer health effects that can be posed by air exposures over short-term or acute exposure durations, using sources of toxicity information in accordance with OSWER's hierarchy (EPA 2003). Although the indoor air concentrations may vary temporally, an appropriate exposure concentration estimate (e.g., time-integrated or time-averaged indoor air concentration measurement in an occupied space – see Section 6.4.1) that exceeds the health-protective concentration levels for acute or short-term exposure (i.e., acute or short-term hazard quotient greater than one) indicates vapor concentrations that are generally considered unacceptable. When indoor air concentrations in an occupied space exceed health-protective concentration levels for short-term or acute inhalation exposures, prompt response action to reduce or eliminate exposure is generally warranted.

7.6 Potential Response Actions

Response actions that may be implemented in existing buildings include:

- Temporary measures (see Section 8.2.1), if prompt action is warranted (see Sections 5.2 and 7.5) and installation of engineered exposure controls in the building(s) would not be timely;
- Engineered exposure controls (see Section 8.2.2) with associated monitoring and institutional controls (see Section 8.6), as an interim (but potentially long-term) measure; and
- Remediation of the subsurface vapor source (see Section 8.1) with associated monitoring and institutional controls (see Section 8.6).

Response actions that may be warranted in buildings that may be constructed in the future include:

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[79] NIOSH has designated such concentrations as immediately dangerous to life or health (IDLH).

[80] Although the building-specific data may vary temporally, any short-term exceedance of one-tenth of the LEL indicates vapor concentrations that, given an ignition source and available oxygen, may be capable of causing an explosion.

- Remediation of the subsurface vapor source (see Section 8.1) with associated monitoring and institutional controls (see Section 8.6); and
- Institutional controls (see Section 8.6) to require building mitigation (see Section 8.2.2) and/or to require a confirmatory vapor intrusion investigation before the building is occupied, in case the building is to be or may be constructed before subsurface vapor sources are remediated to cleanup levels.

Indoor air monitoring has frequently been selected as a response action in circumstances where subsurface vapor sources are present and the vapor intrusion pathway has not been shown to be incomplete. Indoor air monitoring may be deemed warranted, for example:

- To better characterize spatial or temporal variability;
- To address uncertainty in the characterization of the vapor intrusion pathway when subsurface sources have the potential to pose a health concern in overlying or nearby buildings (e.g., incomplete pathway characterization, concern about the potential for changes in building conditions, discordant lines of evidence); or
- For other site-specific or situation-specific reasons.

8.0 BUILDING MITIGATION AND SUBSURFACE REMEDIATION

This section summarizes information and guidance on potential options to mitigate and manage vapor intrusion. It is organized as follows:

- Section 8.1 summarizes the role of subsurface remediation in mitigating vapor intrusion.
- Section 8.2 provides an overview of engineered exposure controls (i.e., building mitigation technologies) for existing and new buildings.
- Sections 8.3 and 8.4 summarize guidance about operating and monitoring building mitigation systems, respectively.
- Section 8.5 summarizes guidance about documenting building mitigation systems.
- Section 8.6 describes and provides guidance about institutional controls.
- Section 8.7 provides guidance about exit strategies (e.g., termination of: subsurface remediation for vapor source control; building mitigation system operation; and associated ICs).

Sections 5.2, 7, and 9 discuss potential bases for deciding to implement vapor intrusion mitigation measures.

8.1 Subsurface Remediation for Vapor Source Control

The preferred response to the intrusion of vapors into buildings is to eliminate or substantially reduce the level of contamination in the subsurface source media (e.g., groundwater, subsurface soil, sewer lines) by vapor-forming chemicals to safe levels, thereby achieving a permanent remedy. Remediation of the groundwater plume or a source of vapor-forming chemicals in the vadose zone will eventually eliminate potential exposure pathways and can include the following actions:

- Removal of contaminated soil via excavation;
- Removal of contaminated groundwater with pump-and-treat approaches; and
- Remediation of contaminated soil and groundwater *in situ*, using technologies such as soil vapor extraction, multiphase extraction, air sparging, and bioremediation, or natural attenuation.

In some cases, non-engineered controls or ICs, such as zoning or deed restrictions, and/or resident relocation may accompany implementation of vapor source remediation methods (EPA 2008c). Because there is a substantial body of EPA guidance on remediation of subsurface vapor sources (e.g., NRC 2004; EPA 1993b, 2006c), it is not discussed further here.

8.2 Building Mitigation for Vapor Intrusion

In cases where subsurface vapor sources cannot be remediated quickly, it may be appropriate to also undertake (interim) measures in individual buildings (i.e., building mitigation for vapor intrusion) to promptly reduce threats to human health in occupied buildings. EPA recommends that building mitigation for vapor intrusion be regarded as an interim action that can provide effective human health protection. Vapor intrusion mitigation of buildings should not be viewed as a substitute for remediation of subsurface vapor sources. EPA recommends that building mitigation generally be conducted in conjunction with vapor source remediation where at all possible.

The purpose of this section is to provide an overview of vapor intrusion mitigation for new and existing buildings where building mitigation is determined to be warranted. Section 8.2.1 summarizes temporary measures that generally can be implemented relatively quickly to reduce indoor air concentrations. Section 8.2.2 identifies and summarizes the most commonly implemented engineered control methods for existing buildings. Section 8.2.3 identifies and describes some approaches and considerations for addressing vapor intrusion for new buildings. Additional detailed information about vapor intrusion mitigation technologies and their selection, design, operation, and monitoring is provided in other EPA documents (EPA 1993a, 2008c, 2013b).

8.2.1 Temporary Measures for Existing Buildings

If measured indoor air concentrations are elevated or expected to be elevated (e.g., sub-slab concentrations are higher than target screening levels) and mitigation will be delayed or require substantial planning to complete, it may be appropriate to implement *temporary measures* in advance of permanent building mitigation solutions. Temporary measures may include:

- Increasing building ventilation, for example using fans or natural ventilation;
- Sealing major soil gas entry routes;
- Treating indoor air; and
- Evacuation, which may include temporary re-location.

Each of these options is summarized in the remainder of this section.

Increasing building ventilation (i.e., increasing the rate at which indoor air is replaced with outdoor air) can reduce the buildup of indoor air contaminants within a structure. Natural ventilation may be accomplished by opening windows, doors, and vents. Forced or mechanical ventilation may be accomplished by using a fan to blow air into or out of the building. Increased ventilation is easiest and least costly to implement in locations where the air is not conditioned (heated or cooled). If indoor air is conditioned, increased ventilation can be a costly option because the conditioned air is ventilated to the outdoors. This drawback can be partly overcome by use of heat exchangers, but they are also costly. Another concern is that exhausting air from the building will generally contribute to under-pressurization of the building, relative to the subsurface, thereby potentially resulting in an increased rate of soil gas entry (i.e., vapor intrusion) unless ambient air entry into the building is increased equivalently. In some cases, ventilation may not be capable of reducing indoor air concentrations to acceptable levels. In addition, building occupants may find it uncomfortable to increase the air exchange rate by more than a factor of three or four.

Vapor intrusion into the building can also be reduced by sealing foundational openings using products such as synthetic rubbers, acrylics, oil-based sealants, asphalt/bituminous products, swelling cement, silicon, or elastomeric polymers. The selected sealants should be screened to make sure they do not contain or emit vapor-forming chemicals that might pose a health risk to building occupants. This mitigation approach is among the easiest and least expensive to implement. In some cases, sealing openings may not be capable of reducing indoor air concentrations to acceptable levels.

Commercially available indoor air cleaners include both in-duct models and portable air cleaners. These devices operate on various principles, including zeolite and carbon sorption and photocatalytic oxidation. Methods that rely on adsorption generate a waste that must be disposed of appropriately or regenerated and require periodic replacement of the adsorption medium.

For buildings with potential explosion and fire hazards, EPA recommends evacuation, along with notification of the local fire department about the threat. Evacuation may also be implemented for buildings where the results of indoor testing reveal potentially toxic conditions warranting prompt response action.[81]

8.2.2 Engineering Controls for Existing Buildings

This section provides a brief overview of engineered vapor intrusion mitigation technologies that can be used in existing buildings, along with a summary of steps and considerations for selecting an appropriate mitigation method for a given building. The focus is on active depressurization technologies most commonly employed for building mitigation. This focus does not mean, however, that active depressurization technologies are always preferred over other mitigation methods or that they will be the best option for every site. More detailed information on vapor intrusion mitigation systems for existing buildings, including passive technologies,[82] can be found in several EPA publications (e.g., EPA 2013b, 2008c).

Active depressurization technologies (ADT) have been used successfully to mitigate the intrusion of radon into buildings and have also been successfully installed and operated in residential, commercial, and school buildings to control vapor intrusion from subsurface vapor-forming chemicals. ADT systems are widely considered the most practical vapor intrusion mitigation strategy for most existing buildings, including those with basement slabs or slab-on-grade foundations. ADT systems are generally recommended for consideration for vapor

[81] OSWER Directive 9230.0-97 (*Superfund Response Actions: Temporary Relocations Implementation Guidance* (EPA 2002d)) provides policy and recommended procedures for temporarily relocating residents during response actions carried out under Sections 104(a) and 106(a) of CERCLA.

[82] Engineered exposure controls that do not involve mechanical operations (e.g., creating a barrier between the soil and the building that blocks entry routes from the soil gas into the building) are referred to as “passive.”

intrusion mitigation because of their demonstrated capability to achieve significant concentration reductions in a wide variety of buildings[83] and their moderate cost.

Sub-slab depressurization (SSD) systems, a common type of ADT system, function by creating a pressure differential across the building slab to prevent soil gas entry into the building (i.e., overcoming the building's natural under-pressurization, which is the driving force for vapor intrusion). Creating this pressure differential is accomplished by extracting soil gas from beneath the slab and venting it to the atmosphere.[84] Construction of SSD systems entails opening one or more holes in the existing slab, removing soil from beneath the slab to create a "suction pit" (6–18 inch radius), placing vertical suction pipes into the holes, and sealing the openings around the pipes. These pipes are then connected together to a fan, which draws soil gas from the sub-slab area through the piping and vents it to the outdoors. SSD systems were first developed for radon reduction and operate under similar design principles as radon mitigation methods.

When sumps and associated drain tile systems are present, they may also be depressurized to prevent soil gas entry into the building (again, overcoming the building's natural under-pressurization). This variation on active depressurization is often referred to as drain-tile depressurization (DTD). Depressurization of drain tiles located near a foundation wall can help control soil gas entry at the joint between the foundation wall and slab.

If the building has hollow block walls, the usual sub-slab suction point may not adequately mitigate the wall cavities, which may be particularly important if the outside surfaces are in contact with the soil. In these situations, the void network within the wall may be depressurized by drawing air from inside the wall and venting it to the outside. This method, called "block-wall depressurization" (BWD) is often used in combination with SSD. Because uniform depressurization of block walls can be difficult and in some cases counterproductive, BWD is generally recommended only when sub-slab or DTD prove inadequate to control vapor intrusion.

In buildings with a crawl space foundation or a basement with a dirt floor, a flexible membrane may be installed over the floor to facilitate depressurization of the soil gas beneath the membrane, which prevents its intruding into the crawl space or basement air. For such sub-membrane depressurization (SMD) system to be effective, the membrane should cover the entire floor area and be sealed at all seams and penetrations.

Extensive guidance is available for the design, sizing, installation, and testing of ADT systems for radon control in existing and new homes and large institutional (e.g., school) and commercial buildings. EPA recommends that ADT systems be designed and installed by qualified persons,

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[83] Folkes and Kurz (2002) describe a case study of a vapor intrusion mitigation program in Denver, Colorado. Sub-slab depressurization systems and/or sub-membrane depressurization systems were installed in 337 residential homes to control indoor air concentrations of 1,1-dichloroethene (DCE) resulting from migration of vapors from groundwater with elevated 1,1-DCE concentrations. Over three years of monitoring data for 301 homes have shown that these systems are capable of achieving the very substantial reductions in concentrations required by state standards. Approximately one quarter of the systems required minor adjustment or upgrading after initial installation in order to achieve the state standards.

[84] Governmental permits or authorizations may be required for venting systems that exhaust to the atmosphere.

typically environmental professionals and licensed radon contractors. EPA guidance for design of ADT systems can be found in several publications (EPA 1993a, 2008c, 2013b).

EPA guidance for selecting, designing, and installing vapor intrusion mitigation systems for existing buildings can be found in *Technical Basis for the Selection, Design, Installation and Operation & Maintenance of Vapor Intrusion Mitigation Systems* (EPA 2013b). The vapor intrusion Mitigation Quick Guide provided in Table 8-1 summarizes a list of steps for selecting and implementing a vapor intrusion mitigation system in existing buildings, which have been excerpted from this document.

The U.S. Navy issued a concise fact sheet that also contains useful technical information (DoN 2011b).

TABLE 8 1
VAPOR INTRUSION MITIGATION QUICK GUIDE FOR EXISTING BUILDINGS

Step 1: Consider Temporary Measures

It may be appropriate to implement temporary measures before engineered controls are constructed and operated, as warranted and feasible. The owner/tenant can, for example, increase building ventilation, seal cracks and other entryways for soil gas in the floor or foundation, or conduct indoor air treatment (refer to Section 8.2.1).

Step 2: Select a Building Mitigation System (EPA 2013b)

The selection of a vapor intrusion mitigation system primarily depends on building characteristics and contaminant concentrations. In the majority of cases, the most efficient, reliable, and cost-effective vapor intrusion mitigation technique selected will be (or include) a type of active depressurization technology (ADT). In some cases, however, other approaches can or should be considered.

The initial step in selecting the appropriate vapor intrusion mitigation technology is to conduct a visual inspection of an existing building. Factors that may prompt consideration of vapor intrusion mitigation approaches other than ADT include: a tight basement, a tight or inaccessible crawl space, and a well-drained, gravelly native soil.

If there are no factors that would rule out an ADT technology, appropriate systems that can be considered include:

- Sub-slab depressurization (SSD) systems, particularly in houses having slabs (basements and slabs on grade) where drain tiles are not present.
- Drain-tile depressurization (sump/DTD or remote discharge/DTD) when drain tiles are present.
- Sub-membrane depressurization (SMD) in buildings with a crawl space foundation or a basement with a dirt floor,
- Block-wall depressurization (BWD), usually used only as a supplement to SSD, DTD, or SMD to better mitigate vapors found to be migrating through the wall.

Step 3: Design Building Mitigation System (EPA 2013b)

A visual inspection will provide, in most cases, the information needed for effective design of an ADT system. In some cases, however, additional pre-mitigation diagnostic testing will be needed to facilitate design of an effective ADT system. The detailed design of the selected vapor intrusion mitigation technology generally should consider information about the number and location of suction points, location and size of piping, suction fan, piping network and exhaust system, and sealing options to be used in conjunction with the ADT technology.

Step 4: Install Building Mitigation System (EPA 2013b)

EPA recommends that the vapor intrusion mitigation system be installed in accordance with manufacturer's design specifications and local permit requirements and regulations.

Step 5: Confirm the Installed System is Operating Properly (EPA 2013b)

EPA recommends a visual inspection of the installed system as a routine quality assurance step to confirm that all construction details have been completed. Post-construction diagnostic tests are recommended, even when the ADT system appears (visually) to be operating appropriately. Where a vapor intrusion mitigation system is not performing adequately, post-construction diagnostic tests can be helpful in trouble-shooting.

Step 6: Ensure Proper Operation and Maintenance of Vapor Intrusion Mitigation System (refer to Sections 8.3 and 8.4)

EPA recommends proper system maintenance and periodic inspections to ensure the system is operating as designed and is effective at reducing indoor air concentrations to (or below) target levels. EPA site managers should provide the owner/tenant with information to help ensure proper operation and maintenance of the system.

EPA recommends that periodic inspections include periodic measurements to confirm that the building mitigation system is continuing to perform adequately.

8.2.3 Approaches and Considerations for New Buildings

The ADT systems described above are generally applicable to new buildings. However, a wider array of approaches and technical options is typically available to mitigate or avoid vapor intrusion for new buildings, compared to existing buildings. These options potentially include choice of building location and opportunities to modify the building design and construction, which are not available for existing buildings. For example:

- At some sites, contaminated areas most likely to produce unacceptable vapor intrusion exposures can be avoided and designated for another purpose, such as recreational space or undeveloped landscape.
- Mitigation needs can also be considered in the selection of heating and cooling systems, which are normally selected based only on economics, aesthetics, preference, and custom. A system design that avoids creating under-pressurization inside the structure and maintains over-pressurization inside the structure may be effective in mitigating vapor intrusion.
- Passive barriers, such as a low-permeability membrane, can be more readily installed between the soil and the building during new building construction. Passive barriers are intended to reduce vapor intrusion by limiting entry routes. Passive barriers as stand-alone technologies may not adequately reduce vapor intrusion owing to difficulties in their installation and the potential for perforations of the barrier during or after installation. They are commonly combined with ADT systems or with sub-membrane ventilation systems to help improve their efficiency.
- Venting layers can be more readily installed between the soil and the building during new building construction.[85]
- Sometimes, new buildings can be designed to include a highly ventilated, low-occupancy area at ground level, such as an open parking garage.

Steps 2-6 of the Vapor Intrusion Mitigation Quick Guide provided in Table 8-1 are also pertinent to newly constructed buildings. EPA guidance for selecting, designing, and installing vapor intrusion mitigation systems for new buildings can be found in several publications (EPA 2008c, 2013b). The U.S. Navy issued a concise fact sheet that also contains useful technical information (DoN 2011c).

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[85] Sub-slab ventilation systems typically consist of: a venting layer (e.g., filled with porous media such as sand or pea gravel; or suitably fabricated with continuous voids) below a floor slab to allow soil gas to move laterally to a collection piping system for discharge to the atmosphere; and a sub-slab liner that is installed on top of the venting layer to reduce entry points for vapor intrusion. Sub-slab ventilation systems function by drawing outside air into the sub-slab area, which dilutes and reduces concentrations of vapor-forming chemicals and providing a pathway to allow soil gas to migrate outside the building footprint rather than into a building.

8.2.4 Owner/Occupant Preferences and Building Access

Building owners and occupants can initially be notified in various ways that their home or building has been selected for a building mitigation system. Section 10.5 provides guidance regarding such notifications and other messages pertaining to building mitigation.

Whereas EPA managers and mitigation system designers may be primarily concerned with the performance, cost-effectiveness, and reliability of any mitigation system, the building owners and occupants may have additional perspectives and opinions that warrant consideration during technology selection, design, construction, and operation. For example, owners and tenants will often have strong opinions about where fans and piping are located, what level of fan noise is acceptable, and what quality of construction craftsmanship is satisfactory. When there are multiple mitigation options (for example, at a large commercial building), these options should be presented fairly to the building owner and occupants, explaining the advantages and disadvantages associated with each and describing the rationale for the preferred alternative.

In some cases, obtaining and scheduling access to a building can be difficult, whether the structure is a commercial or institutional building or a private residence. Commercial building tenants may not want construction activities disrupting business operations. Some homeowners may resist granting access to their home. Other homeowners may prefer to schedule tests before or after their work-day. To address these practical and logistical concerns, EPA recommends that an access agreement(s) be executed between the property owner, any tenants, and the mitigating entity to ensure appropriate access as needed to operate, maintain, and monitor the engineering exposure controls in each applicable building.

8.3 Operation and Maintenance of Vapor Intrusion Mitigation Systems

For purposes of this guidance, operation and maintenance (O&M) is used generically to refer to periodic inspections, component maintenance or replacements, repairs, and related activities that are generally necessary to ensure continued operation and effectiveness of engineered exposure controls to mitigate vapor intrusion. EPA generally recommends that such O&M activities be conducted routinely. The nature and frequency of O&M activities should consider manufacturer's recommendations and site-specific factors. Additional information about ensuring continued effectiveness of systems is available in EPA (2009b).

Design specifications for vapor migration systems may include (1) a maintenance frequency that varies over the operating period of the mitigation system and/or (2) a provision to evaluate and modify the frequency based on data or information obtained during monitoring and maintenance. For example, it may be acceptable to reduce inspection or maintenance frequency once efficient system operation has been demonstrated for at least an initial year, with triggers for additional, unscheduled inspections following alarms (from warning devices) and floods, earthquakes, and building modifications, as needed.

Typical O&M activities for either passive or active systems may include, but are not limited to:

- Routine inspection of all visible components of the vapor intrusion mitigation system, including fans, piping, seals, membranes and collection points, to ensure there are no signs of degradation or blockage. EPA recommends that the as-built drawing for the vapor intrusion mitigation system be examined to verify the system configuration has not been modified.

- A crawl space SMD membrane may require repair or replacement if its integrity is compromised. Visual inspection of the building to evaluate whether any significant changes were made (such as remodeled basement, new furnace) that would affect the design of the vapor intrusion mitigation system or the general environment in which it is operated.

- Visual inspection of the area of concern (including basement floor and wall seals, sumps, floor drains and utility penetrations) to ensure there are no significant changes in conditions that would require modification of the system design.

- Routine monitoring of vent risers for flow rates and pressures generated by the fan to confirm the system is working and moisture is draining correctly.

- Routine maintenance, calibration and testing of functioning components of the venting system in accordance with the manufacturers' specifications.

    - Pressure readings for both active and passive depressurization systems as well as positive pressurization systems (e.g., periodic verification of measurable pressure differentials across the slab).

    - Confirmation that the extraction fan is operating.

    - SSD system fans generally do not require routine maintenance; however, fans should be replaced as necessary throughout the operating life of the system (generally every 4 to 10 years).

- Inspection of external electrical components to determine excessive noise, vibration, moisture, or corrosion and that the fan cut-off switch is operable.

    - Inspection of the fan(s) is important throughout the operating period but may be particularly important near the end of its expected lifespan. Noisy fans typically indicate problems with ball bearings and should be replaced.

    - Confirmation of adequate operation of the warning device or indicator.

- Confirmation that building owner/occupants are knowledgeable about how to maintain system operation. Confirmation that a copy of the O&M manual is present in the building and has been updated as necessary.

In addition to the physical inspection of the system and its operation, EPA also recommends that the site team determine if there has been any change in ownership/tenant. If a change has occurred, the site manager should work with the new owner/tenant to ensure continued integrity of the vapor intrusion mitigation system.

8.4 Monitoring of Vapor Intrusion Mitigation Systems

EPA recommends that any long-term monitoring program consider the degree of risk or hazard being mitigated, the building use, and the technology used to mitigate vapor intrusion. For example, an older building with highly volatile contaminants at high concentrations may need a higher level of monitoring than a new building with lower concentrations of less volatile contaminants. In addition, passive systems are generally less predictable and less efficient at preventing vapor intrusion than active systems and therefore typically require more monitoring. Examples of various monitoring scenarios are provided in Table 4 of CalEPA (2011), Table 6-2 of NJDEP (2012), and Table 3-1 of MADEP (2011).Un-mitigated buildings adjacent to properties with mitigation systems may also warrant periodic review or monitoring to verify that vapor intrusion is not occurring or resulting in indoor air concentrations exceeding action levels. 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 indoor air sampling, sub-slab vapor sampling, or soil gas monitoring. Ensuring protectiveness through long-term monitoring activities may be conducted by the owner of the building, the PRP, or the regulatory authority, depending on who has the responsibility to conduct such monitoring. Additional information about ensuring continued effectiveness is available in the *Operational and Functional Determination and the Transfer of Fund-lead Vapor Intrusion Mitigation Systems to the State* (EPA 2009b).

Pressure Measurements

Sub-slab probes can also be used to monitor differential pressures for a direct indication of the performance of ADT systems. While the pressure differential between the indoor and ambient air at ground level may serve as an acceptable surrogate, it is the pressure differential across the slab that prevents soil gas entry. For basements, the walls that are underground become part of the critical building envelope that must prevent soil gas entry. For subsurface depressurization systems, EPA recommends that the pressure gauge be monitored quarterly to verify the system is operating efficiently. A reduced monitoring frequency may be appropriate after one year of successful operation of the remedial system.

Leaks within the building or mitigation system can affect the pressure measurements. Tracers can be used either for leak detection through barriers, building materials or system components (piping, for example) or to measure the air exchange rate in the building, as discussed previously. Smoke testing is a qualitative form of tracer testing used to detect leaks (e.g., at seams and seals of membranes in SMD systems or at potential leakage points through floors above sealed crawl space systems or preferential vapor migration pathways), or to test airflow patterns. A limitation of smoke testing in existing structures is that non-noxious smokes are expensive, and cheaper high-volume smoke sources can leave undesirable residues. The efficacy of smoke testing in some applications has been questioned on the grounds that many leaks are too small for visual detection using this method (Maupins and Hitchins 1998, Rydock 2001), and that leaks large enough to detect using smoke could be detected other ways. More quantitative methods have been recommended, such as tracer testing with instrumentation for quantitative results.

Air Sampling

Once an adequate demonstration of vapor intrusion mitigation system effectiveness has been made, indoor air quality should generally be acceptable as long as an adequate pressure differential is maintained. EPA recommends that indoor air samples be collected at least once a year to confirm that the vapor intrusion mitigation system is continuing to perform adequately, unless site conditions warrant a different monitoring schedule based on system performance or building modification. At some sites, it may be more appropriate to conduct indoor air sampling at a subset of the buildings (e.g., 10 percent), while conducting pressure measurements at all of the buildings. More frequent and systematic monitoring programs are advisable for larger and more complex buildings, such as schools.

Weather-Related Considerations

Weather conditions, such as temperature and precipitation, can affect the performance of a vapor intrusion mitigation system and thus, EPA recommends that this be noted during monitoring activities. For example, cold temperatures may increase the depressurization created by the thermal stack effect and thus increase the driving force for soil gas entry, depending upon the height of the house and the temperature difference between indoors and outdoors. As a result, the ADT system may need to overcome more building depressurization than originally considered when designed. Precipitation may also increase moisture in the fill under the slab, which may affect the performance of the system.

Alarms

Alarms generally are used as part of a long-term monitoring plan to ensure that vapor intrusion mitigation systems are functioning properly. According to ASTM (2003), “All active radon mitigation systems shall include a mechanism to monitor system performance (air flow or pressure) and provide a visual or audible indication of system degradation and failure.” This advice should be equally applicable to vapor intrusion mitigation systems for other contaminants. ASTM goes on to say, “The mechanism shall be simple to read or interpret and be located where it is easily seen or heard. The monitoring device shall be capable of having its calibration quickly verified on site.” Such devices may indicate operational parameters (such as on/off or pressure indicators) or hazardous gas buildup (such as percent LEL indicators). EPA recommends that system failure warning devices or alarms be installed on active depressurization systems, and appropriate responses to them should be understood by building occupants. Monitoring devices and alarms should be placed in readily visible, frequently trafficked locations within the structure. The proper operation of warning devices should be confirmed on installation and monitored regularly.

EPA also recommends that permanent placards be placed on the system to describe its purpose, operational requirements, and instructions on what to do if the system does not operate as designed (for example, a phone number to call). The placard should inform the building occupant how to read and interpret the monitoring instruments or warning devices provided. EPA recommends that these placards be placed as close to the monitoring/alarm part of the system as possible, as well as close to the fan or other active parts of the system.

8.5 Documentation of Vapor Intrusion Mitigation Systems

EPA recommends that documentation be provided to building owners and occupants describing the vapor intrusion mitigation system and its associated O&M. This documentation should be provided to the regulatory agency[86] as an O&M plan that indicates which party is responsible for which O&M activities. Additional information about ensuring continued effectiveness is available in *Operational and Functional Determination and the Transfer of Fund-lead Vapor Intrusion Mitigation Systems to the State* (EPA 2009b). Documentation typically is provided to the property owner or tenant in the form of a user's guide suitable to keep lay persons informed about the system and to provide a reference should questions or issues arise pertaining to the system. The O&M manual provides a detailed record about the mitigation system, including sampling data, copies of agreements, and plans, while the user's guide is a brief summary about the operation of the mitigation system, which can be placed near the system for quick access and easy reference. ICs may be necessary to help ensure the continued integrity of the cleanup, and can complement the O&M plan by ensuring that an active system remains operational and passive membranes are not disturbed. Additional information about ICs is provided in Section 8.6.

O&M Plan

O&M plans generally are prepared on a site-specific basis, and they often are particularly useful at sites where:

- Long-term monitoring is needed to verify remedial effectiveness.
- The remedial system requires periodic adjustments and maintenance.
- Risks to human populations would result if the system fails or if site conditions change.
- The conditions that would trigger specific contingent response require ongoing monitoring.

Some site remedial systems may also require the use of a regulatory agency-approved contingency plan or similar corrective action document approved by the regulatory agency to identify conditions that may trigger the need for additional maintenance, collection of additional data, modifications of monitoring frequency, or other responses to ensure the remedy remains effective.

Communication with building owners and occupants about vapor intrusion and the O&M of a vapor intrusion mitigation system is critically important. For example, building owners may be concerned about the electrical costs for operating a system or some other aspect of its operation and decide to turn it off. It is important to communicate that turning off the system may result in harmful indoor air concentrations inside the building.

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[86] For example, the potentially responsible party (PRP) should provide an O&M plan to EPA at PRP-lead Superfund sites.

O&M Manual

The specific contents of the O&M manual that is supplied to the property owner where a vapor intrusion mitigation system is installed will depend on the type of system, but should generally include at least the following information or items:

- Cover letter;
- Description and diagram of final as-built system layout with components labeled;
- Building permits for a vapor intrusion mitigation system;
- Pre- and post-mitigation VOC data;
- Pre- and post-mitigation diagnostic test data;
- Copies of contracts and warranties;
- Proper operating procedures of the system;
- Contact information of the contractor or installer;
- Copy of signed access agreement;
- Copy of vapor mitigation system O&M agreement;
- Copy of pre-mitigation sample result letter;
- Copy of post-construction sample result letter;
- Contact information in case of future questions; and
- Inspection and maintenance requirements.

User's Guide

A user's guide is a brief summary of why a vapor intrusion mitigation system was installed at a property and how the system works, and may include the following: (1) a brief description of the system and its proper range of operation; (2) contact information for the mitigator if the system stops performing properly; and (3) information about routine maintenance required of the owner/tenant. EPA recommends that a user's guide be placed into a clear protective sleeve and attached to the main extraction pipe of the system. An easy-to-read user's guide is especially helpful at rental properties because the guide informs each new tenant about what the system is and why it was installed.

8.6 Use of Institutional Controls

ICs may be used to restrict certain land uses, buildings, or activities that could otherwise result in unacceptable exposure to the vapor intrusion pathway.

Response actions for vapor intrusion may include ICs to restrict land use for protection of human health regardless of whether the vapor intrusion mitigation system provides interim measures to control risks. ICs can be used as either a short-term response until site cleanup goals are reached or as a long-term response when waste remains in place.

General EPA guidance on ICs is provided in *Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites* ("PIME IC Guidance") (EPA 2012e), which should be considered at vapor intrusion sites.

As discussed in the PIME IC Guidance, ICs are non-engineered instruments, such as administrative or legal controls, that help to minimize the potential for human exposure to contamination and protect the integrity of a response action. ICs typically operate by imposing land or resource use restrictions at a given site or by conveying notice to stakeholders regarding subsurface contamination or the possible need to refrain from certain actions that may result in human exposure to hazardous chemicals. For example, ICs may be used to restrict the development and use of properties for certain land uses (e.g., prohibiting residential housing, hospitals, schools, and day care facilities). In some situations, response actions for vapor intrusion may allow unrestricted land use, but use ICs to secure access to a property or require a responsible party to conduct response activities, such as the installation or maintenance of vapor intrusion mitigation systems. ICs may also be used to establish vapor intrusion mitigation requirements for future construction within an area that may pose unacceptable vapor intrusion threats.

As described further in Section 2.2 of the PIME IC Guidance, ICs can be described in four general categories:

- Proprietary controls.
- Governmental controls.
- Enforcement and permit tools with IC components.
- Informational devices.

Proprietary controls, governmental controls, and enforcement and permit tools with IC components typically memorialize and prescribe substantive use restrictions concerning the land or resource use, while informational devices generally operate to provide notice of contamination and any remedial activities to parties. Depending on the nature of the site and the particular jurisdiction in which it is located, certain instruments may not be available or feasible for a particular site. Certain ICs may enable parties to incorporate affirmative obligations into the instrument itself, such as provisions for access, O&M of vapor intrusion mitigation systems, and design requirements for buildings (see Example #3 box below).

8.6.1 Evaluating ICs in the Overall Context of Response Selection

As a site moves through a program's response selection process (for example, a Superfund remedial investigation/feasibility study [RI/FS] or RCRA facility investigation/corrective measures study [RFI/CMS]), EPA recommends that site managers develop assumptions about reasonably anticipated future land uses, risk exposure pathways related to land use, and consider whether ICs will be needed to ensure protectiveness of these uses (both current and reasonably anticipated future land uses) over time. EPA's land use guidance (EPA 1995, 2010c) recommends that the site manager discuss reasonably anticipated future land uses of the site with local land use planning authorities, local officials, property owners, and the public, as appropriate, as early as possible during the scoping phase of the RI/FS, RFI/CMS, or equivalent phase under other cleanup programs.

IC decisions generally should be documented in proposed cleanup plans and in final cleanup decision documents. For example, for CERCLA cleanups, the proposed restriction, and need for ICs should normally be identified in the Proposed Plan for notice and opportunity to comment by potentially affected landowners and the public. Such use restrictions or notices typically are then selected and memorialized in the record of decision (ROD).

In some cases, unanticipated changes in land use may occur after the response action is implemented, which may impact the protectiveness of a completed response action and call into question the effectiveness of the ICs. Alternatively, additional contaminated media and risk pathways, like vapor intrusion, may be identified after a response action was selected, and ICs may be necessary to supplement the previous action. As a result, vapor intrusion may be identified as a potential risk pathway in a subsequent periodic review. In both of these cases, EPA recommends that site managers evaluate options for modifying the original response decision, including the need for new or additional ICs consistent with existing and reasonably anticipated future land uses and other response selection considerations.

8.6.2 Common Considerations and Scenarios Involving ICs

The evaluation of whether an IC is needed at a contaminated site, including one where the vapor intrusion pathway poses a current or potential threat to human health and the environment, is a site-specific determination. One factor that EPA Regional staff should consider while evaluating whether an IC will be needed is whether the site meets unlimited use and unrestricted exposure (UU/UE). UU/UE is generally the level of cleanup at which all exposure pathways present an acceptable level of risk for all land uses, including reasonably anticipated future land use scenarios that are considered during response selection.

When evaluating contaminated sites where a final response action has yet to be selected, the vapor intrusion pathway is generally evaluated as part of, or prior to, the overall site risk assessment. Vapor intrusion assessments, as described in Section 5.0, incorporate qualitative assessment of risk using the multiple lines of evidence approach. Considerations for these sites include the following: the presence of VOCs in subsurface contamination and the presence or potential for development of buildings overlying an area of subsurface contamination.

Common scenarios where ICs may be a useful tool in helping to ensure protectiveness at a site involving vapor intrusion threats include, but are not limited to, the following:

1. Existing buildings overlie soil or groundwater contamination, or a migrating groundwater plume that is moving toward existing buildings potentially poses a future vapor intrusion threat;

2. Future construction is planned or may be planned on a site that overlies subsurface contamination with vapor-forming chemicals;

3. Changes to building construction/design (such as remodeling or ventilation changes) or building use (such as commercial building converted for residential use) potentially affect exposure to the vapor intrusion pathway;

4. Vapor intrusion mitigation systems are needed in buildings, or existing ventilation systems are being utilized for vapor intrusion mitigation, and continued access is required for their O&M;

5. Response actions to reduce source contamination will not immediately meet response objectives; and

6. Response actions to reduce or eliminate source contamination will not be taken (for example, where it is technically impracticable to treat groundwater that is the source of vapor intrusion).

Using ICs may also serve to provide notice to parties, including prospective purchasers, about what land or building uses are compatible with current or future anticipated risks at the site. For example, modifications to a building's ventilation or air conditioning system may affect building pressure in a way that leads to a potential vapor intrusion threat. Various ICs can be tailored to address construction and design requirements of both existing and future buildings—a local ordinance, for example, may require parties to submit a building design to its building department that incorporates mitigation measures as determined appropriate by a Professional Engineer (P.E.) (see IC Example #1).

IC EXAMPLE 1:

City of Mandan, North Dakota Ordinance No. 1002 (City of Mandan 2006)

In 2006, the City of Mandan, North Dakota, enacted an ordinance that created an Environmental Institutional Control Zoning District to define an area of downtown Mandan impacted by petroleum contaminated soil and groundwater and to establish ICs for the protection of human health and the environment. Among other provisions, the ordinance requires any person proposing redevelopment, demolition, excavation, grading, or construction activities at properties within the District to submit to the city administrator or their appointee a contingency plan, approved by the North Dakota Department of Health, to evaluate and manage any petroleum contaminated soils or groundwater and any potential petroleum vapor impacts. The contingency plan must be prepared by a P.E. with experience in the environmental field, and the plan must consider and protect against, among other things, the vapor intrusion pathway. In addition, the ordinance also provides for restrictions on construction of new structures within the District. In pertinent part, the ordinance provides:

"Any person proposing to construct a new structure within the District shall submit a design for that structure that incorporates engineered controls to mitigate the effects of the potential presence of petroleum in the subsurface to the city administrator or their appointee. The design must be prepared by a P.E. and the design must be approved by the North Dakota Department of Health and must meet additional applicable codes and standards relative to the presence of petroleum. The design shall protect the public health and the environment by considering, at a minimum a) historic water/product intrusion; b) historic petroleum vapor/odor issues; c) potential future water/product intrusion; and d) potential future petroleum vapor/intrusion. The design shall incorporate vapor barriers, venting system, groundwater suppression/collection, and specialized HVAC as determined appropriate by a P.E."

In addition to restricting land, building, or resource use, some types of ICs may provide an effective means for addressing long-term O&M at vapor intrusion sites consistent with decision documents and enforcement documents. This could happen, for instance, when an IC requires that mitigation systems be installed and maintained in future construction or if the use of an existing building changes (e.g., industrial building use changes to mixed commercial or residential uses). Provisions regarding access to and periodic maintenance and testing of the mitigation systems, and other site-specific obligations may be incorporated into the IC (see IC Example #2).

IC EXAMPLE 2: State IC Legislation

Some states have enacted statutes that directly authorize proprietary controls for the purpose of preventing use in conflict with environmental contamination or remedies. These state statutes divide into ones modeled after the Uniform Environmental Covenants Act (UECA)[87] and other non-UECA statutes.[88] These UECA and non-UECA state statutes tend to provide advantages over traditional common law proprietary controls by reducing certain legal and management complications associated with their use. The Model UECA, for instance, contemplates that the grantee or "holder" of the "environmental covenant" may be given specific rights or obligations with respect to future implementation of the environmental covenant.[89] This ability to require parties to undertake affirmative actions at a site, such as long-term maintenance of a cap or O&M of a vapor intrusion mitigation system, through a UECA environmental covenant, abrogates traditional common law prohibitions in doing so applicable to common law proprietary controls.

Proprietary controls that bind current and subsequent landowners (that is, the proprietary control "runs with the land") to use restrictions at properties, as well as require them to undertake affirmative obligations, may have utility at vapor intrusion sites. For instance, at a contaminated site in Bucks County, Pennsylvania, an environmental covenant executed pursuant to the Pennsylvania Uniform Environmental Covenants Act contained provisions to address vapor intrusion threats. In addition to provisions for access, annual inspections, compliance reporting, and other requirements related to cleanup activities, parties to the environmental covenant agreed to construct slab-on-grade buildings without basements and install vapor barriers as an engineering control to eliminate the potential for vapor intrusion as part of the eventual development of the property. Further, the environmental covenant provided that engineering plans for the vapor barriers first be submitted to and approved by EPA prior to construction. For examples of environmental covenants executed pursuant to the Pennsylvania Uniform Environmental Covenants Act, Act No. 68 of 2007, 27 Pa. C.S. §§ 6501-6517: http://www.depweb.state.pa.us/portal/server.pt/community/land_recycling_program/20541/uniform_environmental_covenants_act/1034860

8.6.3 Selecting the Right Instrument(s)

When evaluating potential IC instruments, site managers and site attorneys should balance the relative advantages and limitations of IC instruments under consideration—for example, consider legal implementation issues, jurisdictional questions, permanence and enforceability concerns—and select those that best achieve the response objectives (see IC Example #3). EPA guidance on ICs provides detailed considerations regarding the selection of ICs and the

[87] UECA was developed by the National Conference of Commissioners on Uniform State Laws. See: www.uniformlaws.org.

[88] See, for example, Colo. Rev. Stat. § 25-15-320 (2011); Cal. Civ. Code § 1471 (2011).

[89] "Grantee" is a traditional property law term describing a person to whom property is conveyed. States that have passed legislation based on UECA have created different legal concepts specific to those jurisdictions. For example, UECA jurisdictions typically define "holder" and "environmental covenant" to reflect, respectively, the grantee and the servitude that imposes the land or resource use restrictions. The model UECA provides that "[h]older means the grantee of an environmental covenant…" See definition 6 in Section 2.0 of the model UECA.

IC EXAMPLE 3: Efforts to Address VI at the Middlefield-Ellis-Whisman Study Area

The Middlefield-Ellis-Whisman (MEW) Study Area is composed of four separate CERCLA sites—Raytheon Corp., Intel Corp. (Mountain View Plant), Fairchild Semiconductor Corp. (Mountain View Plant), and portions of the former Naval Air Station Moffett Field Superfund site—and many distinct parcels with land uses including residential, commercial, and light industrial. In 2009, EPA finalized a Supplemental FS for the MEW Study Area that presented an evaluation of a variety of remedial alternatives that could be used to mitigate potential vapor intrusion into current and future buildings overlying the shallow plume of contaminated groundwater. The FS provided an analysis of ICs using the NCP evaluation criteria: overall protection of human health and the environment; long-term protectiveness and permanence; compliance with applicable or relevant and appropriate requirements; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost. The other two NCP evaluation criteria, state acceptance and community acceptance, were evaluated in the ROD Amendment for the vapor intrusion pathway remedy at the MEW Study Area.

In 2009, EPA published the Proposed Plan for the MEW Study Area that identified EPA's preferred alternatives for the vapor intrusion remedy. The Proposed Plan identified the adoption of a municipal ordinance as EPA's preferred IC, but the City of Mountain View and concerned property owners raised concerns that this was not necessary. Instead, EPA worked with the City of Mountain View, California, to have the City formalize its permitting procedures that apply to future construction. These procedures include requirements that those proposing new building construction within the MEW Study Area obtain EPA approval of construction plans to ensure that, where necessary, the appropriate vapor intrusion control system is integrated into building construction. In a 2010 ROD Amendment, EPA presented its selected remedy for the vapor intrusion pathway for the MEW Study Area. The ROD Amendment identified a combination of ICs for use at the site. In place of a municipal ordinance as called for in the Proposed Plan, the ROD Amendment selected reliance upon the internally modified permitting procedures by the City of Mountain View's Building, Planning, and Permitting Departments. The City will also implement remedy requirements for projects subject to the California Environmental Quality Act through that law's procedures. With regard to existing commercial buildings where an active remedy is necessary, EPA selected the use of recorded agreements that will help provide notice to current and future owners and occupants, notice to EPA and the MEW Companies when there is a change in building ownership or configuration, and the necessary access to install, maintain and operate the vapor intrusion remedy. These agreements will be binding on and enforceable against future property owners. Additionally, EPA selected the use of a tracking service to provide notice when changes are made to properties within the MEW Study Area. Additional controls that will be implemented by the City of Mountain View include creation of a mapping database to help ensure that parties interested in properties within the MEW Study Area are informed of the appropriate construction requirements when making inquiries with the City.

For more information on the MEW Study Area, see the *Final Supplemental Feasibility Study for the Vapor Intrusion Pathway* (June 2009), *Proposed Plan for the Vapor Intrusion Pathway* (July 2009), and *Record of Decision Amendment for the Vapor Intrusion Pathway* (August 2010), available at: www.epa.gov/region9/mew relative strengths of the different categories of IC instruments.[90] Ultimately, the selection of ICs is a site-specific evaluation based on the characteristics of the site (for example, the nature and extent of the vapor intrusion threat) and the particular jurisdiction in which it is located. There are times when multiple IC instruments can be “layered” to best ensure protectiveness of the response action while meeting the response objectives outlined in the decision documents.[91]

Because many ICs are created pursuant to state and other non-federal laws, the authority to implement and otherwise oversee many ICs resides with government entities other than EPA. Units of local governments, for instance, typically have jurisdiction to implement, maintain, enforce, and terminate certain governmental controls, such as zoning ordinances and building permit requirements. Therefore, it is normally very important to evaluate the capacity (financial, technical, etc.) and willingness of the entity ultimately responsible for taking over IC responsibilities prior to IC selection.[92] Site managers and site attorneys are encouraged to coordinate early with IC stakeholders so that adequate assurances may be acquired and then subsequently maintained as necessary over time.

Given the potential role of non-EPA entities, it may be appropriate for EPA to facilitate or recommend a process by which IC stakeholders provide similar assurances or otherwise reach a common understanding[93] regarding their respective IC responsibilities to ensure that selected ICs are effectively implemented, maintained, and enforced. At a vapor intrusion site, for example, a zoning ordinance may be effective in preventing or ensuring responsible future development of properties overlying a contaminated groundwater plume that presents a vapor intrusion pathway threat. Such zoning ordinances generally are designed and enacted by the local government. Once enacted, the ordinance must be followed and enforced for it to serve as an effective IC over its lifespan. One inherent limitation of governmental controls, however, is that their implementation, modification, and termination generally follow a legislative process outside the authority of EPA that may raise questions regarding the reliability and continued effectiveness of the IC. Obtaining early and continued assurances from a local government specifying its commitment to the governmental control is recommended to help address this limitation prior to its selection as the relied upon IC.

Certain IC instruments may not be available for use at a site, depending on federal, state, local, tribal, or other applicable laws. Therefore, after determining the universe of ICs available for use at a particular site, the practical and legal limitations should be evaluated. For example, large sites with widespread contamination pose unique IC challenges. This could happen, for instance, where a contaminated groundwater plume underlies many distinct parcels with multiple property owners/tenants and vapor intrusion is the exposure pathway of concern.

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[90] See Site Manager’s IC Guide and Section 3.2 of the PIME IC Guide for a framework to consider when deciding among available ICs.

[91] See Section 3.2 of the PIME IC Guide for more discussion on layering ICs.

[92] See Section 3.8 of the PIME IC Guide on IC stakeholder capacity considerations.

[93] Parties may be able to provide assurances or otherwise reach a common understanding regarding their respective IC roles and responsibilities through various mechanisms that may be available under state law (for example, a Memorandum of Understanding, Memorandum of Agreement, Administrative Order on Consent, contract, City Resolution, or enforceable agreement, etc.). For additional discussion about obtaining or memorializing IC assurances, see Sections 3.3, 3.8, and 4.3 of the PIME IC Guide.

Negotiating and implementing proprietary controls with many property owners, some of whom may not be PRPs, may present legal, administrative, and other challenges.[94]

8.6.4 Long-term Stewardship

Long-term stewardship (LTS) activities are intended to help ensure that cleanups remain protective of human health and the environment over time and that reuse activities remain compatible with residual site contamination and associated risks. LTS procedures vary widely, but they generally are intended to help assure compliance with the response actions at the site, including IC compliance, by providing relevant information in a timely manner to stakeholders who may use the property (e.g., landowners, excavators, developers, prospective purchasers or tenants) or to parties who otherwise have IC responsibilities (i.e., an entity with enforcement authority). LTS procedures, for example, may entail provisions to monitor and then inform those responsible for the response actions of potential changes in land use, ownership, tenancy, or building construction at a site. Also, LTS procedures may help monitor IC(s) so that they remain effective and reliable over time. EPA guidance on ICs generally speaks to LTS procedures in terms of IC maintenance[95] and enforcement activities.[96]

Periodic Reviews

A key part of IC maintenance is a periodic process over the IC life cycle to critically review and evaluate the IC instrument(s). Site managers and other stakeholders can evaluate the status of IC implementation, maintenance and enforcement activities at a site and address any potential IC deficiencies during the periodic review. The CERCLA FYR process,[97] for example, allows site managers to evaluate overall protectiveness of the remedy, including ICs.[98]

A list of possible IC-specific issues arising from any periodic review of a vapor intrusion site may include:

- ICs that are required by the decision documents but are not yet in place;
- ICs that are in place are not attaining compliance with the use restrictions required by the decision documents (e.g., land use not compatible with IC use restrictions);

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[94] See Section 4.4 of the PIME IC Guide for strategies for implementing proprietary controls.

[95] The term “maintenance” generically refers to those activities, such as monitoring and reporting, that ensure ICs are implemented properly and functioning as intended.

[96] See Sections 8 and 9 of the PIME IC Guide discussing IC maintenance and enforcement activities.

[97] See CERCLA section 121(c).

[98] For general FYR guidance, see *Comprehensive Five-Year Review Guidance* (EPA 2001) at www.epa.gov/superfund/cleanup/postconstruction/5yr.htm. For a more detailed discussion on IC considerations during the CERCLA FYR process, see *Recommended Evaluation of Institutional Controls: Supplement to the “Comprehensive Five-Year Review Guidance,”* (EPA 2011c).

- ICs are not identified in the decision documents but are necessary for the remedy to be protective of human health and the environment because of the vapor intrusion pathway; and

- Response selection assumptions change (e.g., toxicity values, risk pathways, or land uses change) and warrant the need for new or different response actions, including additional IC(s).

IC Planning Documents

Responsibilities to monitor and report on IC compliance, among other obligations, may be documented in an Institutional Controls Implementation and Assurance Plan (ICIAP)[99] or other IC-related planning documents.[100] An ICIAP can serve to: (1) document the activities necessary to implement and ensure the long-term effectiveness and permanence of ICs (that is, the IC life cycle); and (2) identify the person(s) or organization(s) who, under state or local law, are responsible for conducting those activities. Some ICs generally fall within the jurisdiction of a particular category of stakeholders. Therefore, in addition to developing a comprehensive planning document, such as an ICIAP, it may be useful for parties who share IC responsibilities (e.g., a responsible party and local government regarding the use of governmental controls, such as an ordinance or permitting system) to reach a common understanding and acknowledge various IC roles and responsibilities in a formalized manner. Where possible, EPA recommends that these types of arrangements among IC stakeholders be documented to describe commonly understood roles and responsibilities for proper and effective monitoring, reporting, and other IC maintenance and enforcement activities.

8.6.5 Community Involvement and ICs

EPA recommends that site managers and site attorneys provide adequate opportunities for public participation (including potentially affected landowners and communities) when considering appropriate use of ICs (EPA 2012f). Those opportunities may include providing appropriate notice and soliciting comments about cleanup plans. Community acceptance of the need for ICs to provide protection from residual contamination and public understanding of the legal requirements for maintaining ICs often are important to the long-term effectiveness of ICs.

8.7 Termination/Exit Strategy

This sub-section focuses on the termination/exit strategy for vapor mitigation response actions. Termination for vapor mitigation activities implemented under CERCLA, RCRA, Brownfields, and federal facilities cleanups can occur when the objectives of these cleanup activities have been met. For purposes of this sub-section, termination refers to the cessation of all activities related to building mitigation, subsurface source control, ICs, and monitoring.

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[99] For further guidance on developing ICIAPs, EPA developed *Institutional Controls: A Guide to Preparing Institutional Control Implementation and Assurance Plans at Contaminated Sites* (EPA 2012f).

[100] For example, other types of documents may address IC-related activities and responsibilities at a site, such as a ROD, O&M plan, and land use control and implementation plan for federal facility sites.

When mitigating vapor intrusion through subsurface source remediation, building mitigation, and ICs, it is important to develop termination criteria, including the rationale for their selection, early in the remedy planning (e.g., alternatives development) process. (Termination criteria generally refer to monitoring data and associated statistics that will be used to demonstrate that contaminant cleanup levels and remedial objectives of the response actions have been achieved.) EPA recommends that these termination criteria be recorded in decision documents, in any other planning reports, and in monitoring reports. EPA generally recommends also developing and documenting an exit strategy, which clarifies how it will be determined that the termination criteria have been attained. This document could be developed in conjunction with the O&M and monitoring plan so that all stakeholders are provided with a clear set of termination criteria for the active remediation (including mitigation systems), ICs, and monitoring plans. If site conditions (e.g., building usage, vapor flux) change during the vapor mitigation activities, it may become necessary to modify the termination strategy.

When reviewing vapor intrusion activities, considerations for evaluating termination activities may include:

- Termination of subsurface remediation activities;
- Termination of engineered exposure controls (building mitigation);
- Termination of the requirement for ICs; and
- Termination of monitoring.

8.7.1 Termination of Subsurface Remediation Activities

Where feasible, the preferred response to address vapor intrusion is to eliminate or substantially reduce the level of volatile chemical contamination in the source media (groundwater and subsurface soil) to levels that eliminate the need to mitigate vapor intrusion at the point of exposure. If subsurface remediation activities are being conducted at the site, termination of these activities will be contingent on demonstrating that the cleanup levels for the subsurface media have been attained. The termination criteria and exit strategy for these remediation activities should be referenced to ensure appropriate data have been collected and evaluated to support termination of these subsurface activities.

In cases where the source cannot be adequately remediated in the short term, it may be appropriate to undertake (interim) measures to reduce short-term threats to human health and the environment.

8.7.2 Termination of Building Mitigation

For purposes of this guidance, “termination of building mitigation” refers to ending the use of an engineered vapor mitigation system. Typically, vapor mitigation is implemented when it is determined that (1) a documented unacceptable risk to inhabitants exists, or (2) the systems were installed as part of an early action strategy (see Section 9 for a discussion of building mitigation as an early action).

Generally, vapor intrusion is addressed using either an active or passive vapor mitigation system. Active mitigation systems generally refer to systems that either mechanically depressurize a sub-slab or pressurize a building or a sub-slab. Passive mitigation systems generally refer to barrier, sealing, or venting systems.

Active Building Mitigation

Generally, building mitigation systems are implemented in conjunction with the investigation and remediation of source(s). Typically, building mitigation systems will be operated until the source(s) are remediated to the cleanup levels that eliminate the need to mitigate vapor intrusion at the point of exposure. The termination/exit strategy should consider contaminant cleanup levels for the source(s). If subsurface vapor source(s) are not remediated, it is generally anticipated that mitigation activities will continue for an extended period of time. As appropriate, the termination strategy may provide criteria for phased evaluation of system cessation as source cleanup levels are achieved.

Generally, once the source is remediated to levels that meet the remedial objectives and protect human health from the vapor intrusion pathway, EPA recommends that the site-specific monitoring data be evaluated to determine if the termination criteria for the building mitigation system have been met. These monitoring data, in part, could be based on data similar to those that were used in a multiple-lines-of-evidence approach for establishing risk or for supporting the decision to undertake preemptive mitigation/early action during the vapor intrusion investigation (e.g., sub-slab soil gas sampling or indoor air sampling). Target concentration(s) that would allow for system termination should be identified and documented, along with recommended monitoring/sampling frequencies. In addition to sub-slab and indoor air sampling, EPA may request that additional site-specific data (e.g., standpipe vapor sampling) be collected to make this determination.

Typically, once it is determined that the building mitigation system may be terminated, there is a period of attainment monitoring. During the attainment period, EPA recommends that the mitigation system be offline so that vapors beneath the structure reach equilibrium and conditions are representative of post-remediation conditions. Additionally, EPA recommends that criteria be established in the exit strategy to determine when ending the attainment monitoring period is appropriate. To develop an exit termination strategy, site-specific fate and transport data may be used to identify an appropriate time period to allow the vapor concentrations to equilibrate. In addition, the termination of the attainment monitoring period may involve an evaluation of the contaminant attenuation rate. The type and frequency of data collected during compliance monitoring should be a site-specific determination.

If the attainment criteria evaluation indicates that cleanup levels and remedial objectives are not being met during the attainment period, it may be necessary to continue or resume mitigation activities. Once it is determined that the cleanup levels and remedial objectives have been met, the active components of the system may be removed from the structure or the owner may elect to continue to operate the system under their own discretion. The mitigator may want to discuss potential benefits of continued operation of the mitigation system (e.g., radon reduction and moisture control). Once the cleanup levels and remedial objectives have been met, all O&M and monitoring required by EPA to ensure system effectiveness can cease.

Passive Building Mitigation

Vapor mitigation for passive systems is accomplished by venting or sealing the sub-slab or crawl space. The termination of passive vapor mitigation systems will typically be similar to the criteria established for the termination of monitoring.

Much like the active mitigation counterpart, passive mitigation systems are typically implemented in conjunction with the investigation and remediation of vapor source(s). Typically, vapor mitigation systems will be operated until the source(s) are remediated to the cleanup levels that eliminate the need to mitigate vapor intrusion at the point of exposure. EPA recommends the termination/exit strategy consider contaminant cleanup levels for the source(s). If source(s) are not remediated, it is generally anticipated that mitigation will continue for an extended period of time. As appropriate, the termination strategy may provide criteria for a phased system termination evaluation as source cleanup levels are achieved. In some instances, these criteria will be sufficient to justify termination of passive system monitoring.

Generally, once the source(s) is remediated to levels that meet the remedial objectives and protect human health from the vapor intrusion pathway, EPA recommends that the site-specific monitoring data be evaluated to determine if the termination criteria have been met. These monitoring data, in part, could be based on similar data to those used in a multiple-lines-of-evidence approach for characterizing the vapor intrusion pathway and human health risk or for supporting the decision to undertake preemptive mitigation/early action during the vapor intrusion investigation (e.g., sub-slab soil gas sampling and/or indoor air sampling). Target concentration(s) that would allow for system termination should be identified and documented, along with recommended monitoring/sampling frequencies.

If the site-specific criteria evaluation indicates that cleanup levels and remedial objectives are not being met, it may be appropriate to evaluate the current system's effectiveness or the possible application of an active mitigation system. Once it is determined that contaminant cleanup levels and remedial objectives have been met, the system will generally not be removed. Instead, all monitoring required by EPA to ensure system effectiveness can cease.

8.7.3 Termination of Requirement for ICs

"Termination of ICs," as used in this guidance, refers to discontinuing the EPA response requirement for the IC because restrictions on land or resource use are no longer necessary to help ensure protectiveness of human health (i.e., prevent unacceptable risks from exposures to vapor intrusion). When developing a termination strategy for ICs that have been selected as part of a response action, the strategy is typically based on data collected from the affected media. Generally, ICs are implemented in conjunction with the investigation and remediation of source(s). It is anticipated that ICs selected and implemented will be needed until (1) source(s) are adequately remediated, or (2) restrictions on land, resource, or building use are no longer necessary based on current and reasonably anticipated future exposure scenarios. This section provides a framework for terminating EPA's requirement for the ICs based on site-specific circumstances relating to vapor intrusion.

Typically, ICs may be necessary until the contaminant source(s) are remediated to the cleanup levels that eliminate the need to mitigate vapor intrusion at the point of exposure. EPA recommends that the exit strategy should consider and identify such cleanup levels for the subsurface vapor source(s). As long as the subsurface vapor source exceeds such cleanup levels, it is generally anticipated that the requirement for ICs will continue. As appropriate, the termination/exit strategy may provide criteria for a phased IC termination evaluation as source cleanup levels are achieved. In some instances, these criteria will be sufficient to justify termination of the requirement for ICs.

Generally, once the source is remediated to levels that meet the remedial objectives and the cleanup levels that are protective of human health from the vapor intrusion pathway, EPA recommends that the site-specific monitoring data be evaluated to determine if the termination criteria have been met. These monitoring data, in part, could be based on data similar to those that were used in a multiple-lines-of-evidence approach for establishing risk or for supporting the decision to undertake preemptive mitigation/early action during the vapor intrusion investigation (e.g., soil gas sampling, sub-slab soil gas sampling or indoor air sampling). Target concentration(s) that would allow for termination of ICs should be identified and documented, along with recommended monitoring/sampling frequencies.

If the site-specific criteria evaluation indicates that terminating the requirement for ICs is appropriate, EPA may conclude that site conditions no longer require that ICs be used as part of the vapor intrusion response. At this point, EPA could notify the applicable entity(s), such as local or state government, tribe, affected landowner, or responsible parties, in writing that EPA's response objectives have been met and that EPA no longer requires the IC to be maintained. As such, EPA's oversight of the IC can cease.

8.7.4 Termination of Monitoring

For purposes of this guidance, monitoring includes activities conducted to verify that the vapor intrusion pathway does not pose a health concern to building inhabitants in the event that no mitigation activities have taken place. This monitoring may be conducted concurrently with subsurface source remediation activities. "Termination of monitoring," for purposes of this guidance, refers to ending any monitoring that was needed to verify that no further mitigation, including IC-related activity, is necessary to protect human health from indoor air exposures posed by vapor intrusion. When developing termination criteria for monitoring, the decision is generally based on data collected from all the affected media.

Monitoring is generally implemented in conjunction with the remediation of subsurface vapor sources(s). EPA recommends that the exit strategy consider cleanup levels for all contaminated media. Typically, monitoring will continue until the source(s) are remediated to cleanup levels that eliminate the need to mitigate vapor intrusion at the point of exposure. If the source is not remediated, it is generally anticipated that any required monitoring will continue. As appropriate, the exit strategy may provide criteria for phased monitoring, resulting in a termination evaluation as source cleanup levels are achieved. In some instances, these criteria are sufficient to justify termination of monitoring.

Generally, once the subsurface vapor source is remediated to levels that meet the remedial objectives and protect human health from the vapor intrusion pathway, EPA recommends that site-specific monitoring data be evaluated to determine if the termination criteria have been met. These monitoring data, in part, could be based on data similar to those that were used in a multiple-lines-of-evidence approach for establishing risk or for supporting the decision to undertake preemptive mitigation/early action during the vapor intrusion investigation (e.g., soil gas sampling, sub-slab sampling, or vapor sampling within potentially affected structures). Target concentration(s) that would allow for monitoring termination should be identified and documented, along with recommended monitoring/sampling frequencies.

If evaluation of the site-specific criteria indicates an increase in subsurface contaminant concentrations, it may be appropriate to evaluate whether the subsurface cleanup plan and the CSM are adequate and appropriate. Once the evaluation of site-specific data indicates that contaminant cleanup levels and remedial objectives have been met, EPA will no longer require this monitoring as part of the response.

9.0 PRE-EMPTIVE MITIGATION/EARLY ACTION

It may be appropriate to implement mitigation of the vapor intrusion pathway as an early action, even though all pertinent lines of evidence have not yet been completely developed to characterize the vapor intrusion pathway for all of the subject building(s), when there is a reasonable basis to believe that vapor intrusion: (1) is occurring or may occur due to subsurface contamination that is subject to federal statutes, regulations, or guidance for environmental protection; and (2) is posing or may pose a health concern to occupants of an existing building(s). Likewise, it may be appropriate and cost-effective to design, install, operate, and monitor mitigation systems (including passive barrier systems) in newly constructed buildings (or buildings planned for future construction) that are located in areas of vapor-forming subsurface contamination, rather than allow vapor intrusion (if any) to occur and address vapor intrusion after the fact. As described in Section 3.4, preemptive mitigation/early action is the term used to describe both situations.

Preemptive mitigation (PEM) should be recognized as an early action that is intended to ensure protectiveness of human health. In this context, mitigation refers to methods that seek to:

- Prevent or reduce vapor entry into a building.
- Reduce or eliminate vapors that have entered a building.

This section discusses PEM for vapor intrusion and addresses statutes, regulations, and considerations affecting its selection and implementation. Several scenarios are described that identify when PEM may be appropriate for implementation. Additional information about vapor intrusion mitigation is provided in Section 8.0. Information and guidance about community engagement pertaining to vapor mitigation, including PEM, is provided in Section 10.0.

Note that the selection and implementation of PEM, when it occurs, is not intended to pre-judge final decisions about remediation of subsurface vapor sources; however, decision-making about PEM should, as appropriate, include a consideration of the potential for long-term O&M and monitoring obligations. In addition, EPA recommends that the selection of PEM be based upon data and information in the administrative record in order to provide an adequate basis for actions undertaken. The administrative record should be supplemented as additional data and information become available.

9.1 Rationale

In ensuring protectiveness of human health, PEM generally may be an appropriate approach to consider for buildings with potential vapor intrusion for a number of reasons, including:

- Building mitigation typically is an effective means of protecting human health and is cost effective for many buildings.
- The potential exposure scenario (inhalation of toxic vapors) or hazard scenario (explosion of vapors) and the attendant adverse consequences cannot generally be readily avoided by building occupants (except by evacuation).

- Involuntary and unavoidable exposures and hazards are generally sources of anxiety and concern for affected building occupants and the general public, particularly when they occur in homes and in the workplace.

- Comprehensive subsurface characterization and investigations of vapor intrusion (to conclusively characterize unacceptable, but variable, levels of vapor-forming chemicals in soil, groundwater, and indoor air, as described in Section 6) can entail prolonged study periods, during which building occupants may be exposed and owners and environmental stewardship groups may remain anxious and concerned about potential indoor air exposures to subsurface vapors in the absence of mitigation.

- Conventional vapor intrusion investigations in and of themselves can be disruptive because such investigations often require indoor access to acquire samples and assess building conditions.

- Mitigation can typically be implemented relatively quickly, while subsurface contamination is being more fully delineated or remediated.

- EPA's experience with residential communities suggests that many affected residents seek and prefer that mitigation systems be installed when vapor intrusion is suspected.

- Mitigation can be a cost-effective approach to help ensure protectiveness of human health during ongoing vapor intrusion investigations to acquire multiple lines of evidence and characterize spatial and temporal variability in subsurface and indoor air concentrations, as well as while subsurface remediation is being planned and conducted to reduce or eliminate subsurface vapor sources.

In summary, PEM based on limited, but credible, subsurface and building data can be an appropriate approach to begin to implement response actions quickly and ensure protectiveness of current building occupants. In such circumstances, resources can be used appropriately to focus first on mitigation of buildings and subsurface remediation, rather than site and building characterization efforts, which may be prolonged. Although PEM may be an effective tool to reduce the exposure and human health risk, building mitigation is not generally intended to address the subsurface vapor source; as such, EPA recommends that it typically be used in conjunction with remediation of the subsurface source of vapor-forming chemicals (e.g., source removal or treatment), as discussed in Section 8.1.

9.2 Statutory/Regulatory Basis for Taking Action with Limited Data

Provisions under CERCLA, RCRA, federal regulations, and federal guidance provide authority and support for taking early actions to mitigate actual and potential human health risks, as discussed below.

9.2.1 CERCLA and the NCP

CERCLA and the NCP both contain provisions that support and encourage taking early actions to mitigate actual and potential threats to human health associated with vapor intrusion. For example, CERCLA sections 104 and 106 provide the federal government with broad authority to take cleanup action to address a release or threatened release of hazardous substances that "may present" a human health risk. Similarly, the preamble to the final NCP issued in the *Federal Register* on March 8, 1990 (55 FR 8704), states, "EPA expects to take early action at sites where appropriate, and to remediate sites in phases using operable units as early actions to eliminate, reduce or control the hazards posed by a site or to expedite the completion of total site cleanup. In deciding whether to take early actions, EPA must balance the desire to definitively characterize site risks and analyze alternative remedial approaches for addressing those threats in great detail with the desire to implement protective measures quickly. EPA intends to perform this balancing with a bias for initiating response actions necessary or appropriate to eliminate, reduce, or control hazards posed by a site as early as possible."

For sites that are not on the NPL, EPA may use its removal authority under CERCLA to undertake early action to mitigate vapor intrusion threats. For sites that are on the NPL, EPA's Superfund program may use its remedial or removal authority under CERCLA to undertake early action to ensure the safety of existing or future property uses that could be affected by vapor intrusion. Building mitigation, subsurface source control, and associated ICs could be part of a final remedy selected for the site, or where appropriate, could represent an early action that (1) is evaluated and selected on a faster track and (2) complements the anticipated final remedial action for the site.

Because of state cost-share consequences, EPA recommends that state concurrence be sought for any Fund-lead PEM under CERCLA where there is a reasonable expectation that the state will need to take over O&M responsibility as part of a long-term, final remedy.

EPA's guidance for preparing Superfund decision documents states: ""Early actions can be taken throughout the RI/FS process to initiate risk reduction activities…. "Early" in this case is simply a description of when the action is taken in the Superfund process. Thus, an early action is one that is taken before the RI/FS for the site or operable unit has been completed. Hence, early actions may be either interim or final" (EPA 1999b). The primary goals of an early action are to "achieve prompt risk reduction and increase the efficiency of the overall site response" (EPA 1992b). Although preparation of an RI/FS Report is not required for an early action, there must be documentation that supports the rationale for the action to fulfill the NCP's Administrative Record requirements. For interim actions, EPA's guidance for preparing Superfund decision documents states: "A summary of site data collected during field investigations should be sufficient to document a problem in need of response. In addition, a short analysis of remedial alternatives considered, those rejected, and the basis for the evaluation (as is done in a focused FS) should be summarized to support the selected action" (EPA 1999b).

At PRP-lead response actions, where the PRP(s) agree to implement PEM, EPA recommends that PRP commitments to proceed with early action be obtained through settlements or other enforcement documents (for example, Unilateral Administrative Order or Administrative Order on Consent). Early action commitments could include performance of long-term O&M and monitoring. EPA recommends that settlement documents with PRPs concerning PEM/early action response actions specify that PRPs agree not to challenge the basis of the response based on inadequate characterization.

9.2.2 RCRA Corrective Action

EPA has emphasized the importance of interim actions and site stabilization in the RCRA corrective action program to control or abate imminent threats to human health and the environment while site characterization is underway or before a final remedy is selected (see the *Federal Register* of May 1, 1996 [61 FR 19446]). Interim actions encompass a wide range of institutional and physical corrective action activities to achieve stabilization and can be implemented at any time during the corrective action process. EPA recommends that interim actions, including PEM, be employed as early in the corrective action process as possible, consistent with the human health and environmental protection objectives and priorities for the site. EPA recommends that, as further information is collected, program implementers continue to look for opportunities to conduct additional interim actions.

9.3 General Decision Framework

To consider PEM, reliable data that support a preliminary analysis, as described in Section 5.0, and risk-based screening, as described in Section 6.5, should be obtained and documented in the administrative record. In appropriate circumstances (e.g., where time is of the essence), a formal health risk assessment need not be conducted to justify selection of PEM, but a preliminary health risk analysis of individual building data or aggregated community data is generally recommended. If there are insufficient data to perform a preliminary risk analysis, but subsurface vapor sources are known to be present near buildings (see Section 5.3), EPA recommends that an appropriate vapor intrusion investigation be conducted to obtain sufficient data.

Sections 5, 6, and 7 provide information and guidance about the types of information obtained and relied upon in assessing vapor intrusion potential and the types of data analyses that can support determinations of whether the vapor intrusion pathway is complete for a specific building or collection of buildings and poses or has the potential to pose a health concern to building occupants. This information and guidance is equally pertinent for supporting final remediation and mitigation decisions and for supporting PEM in accordance with applicable statutes. The premise of PEM, however, is to protect human health first without necessarily waiting to collect all lines of pertinent evidence or multiple rounds of sampling data.

Certain types of subsurface conditions may have greater potential to facilitate vapor intrusion when subsurface sources of vapors are present. These conditions include, but are not limited to:

- Shallow aquifers (for example, five feet or less from the building foundation to the seasonal high water table).
- High-permeability (e.g., gravelly) vadose zone soils that are fairly dry, which are favorable to upward migration of gases.

- Preferential pathways, such as fractured sediments or bedrock, buried streambeds, subsurface drains, and utility conduits, as they can facilitate vertical or lateral migration of vapor with limited attenuation of chemical concentrations.

Under these conditions, it may be easier to determine that PEM may be warranted if a structure is located near a subsurface vapor source that has the potential to pose an unacceptable risk. Other factors to consider include the following:

- Susceptibility to soil gas entry. Some buildings have greater potential for vapor intrusion (i.e., are more susceptible to soil gas entry; see Section 6.3.3) than others. For example, buildings with deteriorating basements or dirt floors generally provide poor barriers to vapor (soil gas) entry. Buildings with sumps or other openings to the subsurface that can serve as preferential pathways for soil gas entry are also more susceptible to vapor intrusion. On the other hand, mobile homes that are not in contact with the ground surface and homes built on stilts without a foundation are generally expected, based upon the physical setting, to be less susceptible to vapor intrusion when subsurface vapor sources are present.

- Actions undertaken or planned to address the subsurface source of vapors. For example, if the source of vapors (e.g., contaminated soil in the vadose zone) is being removed (e.g., excavation of contaminated soil or soil vapor extraction underneath the building) or is to be removed within a time frame that is protective for any potential current or near-term exposures in the overlying or nearby building, then PEM may not be warranted.

9.4 Some General Scenarios Where Preemptive Mitigation May be Warranted

Four general scenarios where PEM may be warranted are summarized below. The first three scenarios address situations where building(s) currently exist, while the fourth scenario addresses a situation where building(s) may be constructed in the future.

9.4.1 Site with Single Building and Limited Data

Figure 9-1a represents a hypothetical scenario where one building is potentially affected by a groundwater plume emanating from a nearby (tractor repair) facility. Because of the rural setting, no other off-site buildings are located nearby that could be included in an assessment of vapor intrusion. As a result, this building would be evaluated for potential vapor intrusion on an individual basis without consideration of data for other buildings. In this case, the site planning team decides to conduct sub-slab soil gas sampling to evaluate whether vapor intrusion has the potential to pose unacceptable risk. Based on the results—the chemical-specific screening levels were exceeded (see Section 6.5)—it may be appropriate to use a PEM approach to install a building mitigation system without conducting a complete site characterization or vapor intrusion investigation. In addition, for example:

- Soil vapor extraction could be conducted at the tractor repair facility.

- Indoor air could be periodically monitored in the on-site building.

- The plume could be monitored as part of remedy planning and selection for contaminated groundwater.

Another example is shown in Figure 9-1b. In this scenario, a dry-cleaning facility is the contaminant source for a localized groundwater plume. Only one building has the potential to be impacted by vapor intrusion based upon the well-delineated, narrow, limited-extent plume. Groundwater data alone (e.g., high concentrations of PCE) would be used to support a decision to conduct PEM at that residence. Indoor air data collected at the dry cleaner and garage are inconclusive because of the presence of potential indoor air sources of PCE (i.e., cleaning compounds and degreasers, respectively). Additional monitoring could be conducted in the dry cleaner and garage. The plume is monitored to verify it is stable and to support remedy planning and selection for contaminated groundwater.

9.4.2 Site with Multiple Buildings and Limited Data

In this scenario, limited data are available for all buildings in a community, but not enough to support a multiple-lines-of-evidence approach for each building. However, when the buildings are evaluated on a site-wide (or area-wide) basis, a more complete data set is available and spatial patterns can be more apparent, which can be used to justify the selection of PEM.

Figure 9-2 shows a hypothetical residential area located near a shopping center that contains an active dry-cleaning facility. Monitoring wells have been installed throughout the neighborhood to evaluate a historical groundwater plume emanating from the dry cleaner that has migrated under the homes and continues to migrate. Groundwater is encountered at approximately 10 feet below ground surface, and site geology consists of various sands. When the buildings are evaluated on a site-wide basis, PEM may be warranted for buildings located above, near, or downgradient of the groundwater plume. In this hypothetical example, a sufficient number of appropriately screened monitoring wells are available to characterize the groundwater throughout the area where buildings are present, but little or no interior data (sub-slab or indoor air) have been collected in individual buildings. PEM may be warranted based on the groundwater concentration data available (i.e., PCE concentrations significantly exceeding screening levels in this example), and the likelihood that the characteristics of the vadose zone will foster vapor migration and intrusion. Note that if a groundwater restoration system is constructed and operated and the plume is thereby contained, the buildings downgradient of the plume may not warrant PEM in the future. In the meantime, an IC may be appropriate for the undeveloped parcel hydraulically down-gradient of the current leading edge of the plume.

9.4.3 Site with Limited Data for Some Buildings But Complete Data For Others

Depending on individual owners and occupants in the affected community, it may be difficult to obtain adequate data for all buildings within a specified area. Challenges include gaining timely access into each building and other practical considerations. The following hypothetical scenario describes one such situation, which is represented in Figure 9-3. In this scenario, the assumption can be made that buildings with similar construction and built about the same time may have similar susceptibility to soil gas entry. It may be appropriate to fully characterize a limited number of buildings considered “reasonable worse case” by collecting multiple lines of evidence and then extrapolating those findings to similar buildings nearby. As a result, it may be determined to use a PEM approach to offer mitigation systems to all buildings within a specified area. Identifying the reasonable worse-case building may be challenging, however, because of numerous factors, such as heterogeneity in the vadose zone, which influences vapor migration paths and rates, and depth to groundwater, which may vary with surface elevation, as well as differences in building construction and any modifications.

9.4.4 Future Construction and Development

If response actions to treat or remove the subsurface vapor source are being conducted or will be conducted before a building is constructed, then building mitigation for the vapor intrusion pathway may not be necessary when the building is constructed or becomes occupied. If current data indicate that there is potential risk of unacceptable vapor intrusion (e.g., " near-source" soil gas), EPA recommends that the remediation decision document record the known facts and data analyses and clearly state that vapor intrusion mitigation or site re-evaluation may be needed when the property is developed or occupied. EPA generally recommends appropriate ICs to ensure enforcement of such remediation decisions.[101]

Prior site use can be particularly relevant where residential development is planned or occurring on property formerly used for commercial or industrial purposes. In these situations, it is not uncommon for residual NAPLs or shallow plumes to remain. Under this circumstance, PEM may be warranted for new construction as a precautionary measure without direct evidence of a vapor intrusion pathway. Incorporating mitigation systems into newly constructed buildings is generally easier to implement and incurs lower cost when compared with retrofitting existing structures.

9.5 Additional Considerations

EPA recommends that the following factors also be considered in evaluating PEM and and determining whether to implement it.

9.5.1 Weighing of Relative Costs of Characterization versus Engineered Exposure Controls

Cost should not be the primary criterion for deciding whether or how to mitigate vapor intrusion because health protection could be compromised. On the other hand, cost effectiveness is addressed by CERCLA and the NCP and can be an important consideration when evaluating response alternatives. Cost can be a factor in deciding when and whether to pursue PEM, in relation to continuing to investigate and assess actual or potential vapor intrusion, and in ensuring effective human health protection through installing and operating a vapor intrusion mitigation system. At PRP-lead sites, for example, PEM may be viewed favorably where the costs associated with a complete site characterization or continued long-term monitoring are estimated to easily exceed the cost of installing a mitigation system (and associated system monitoring). The number of buildings that would need to be characterized, or the order of priority, may be a factor in considering whether to implement PEM.

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[101] At undeveloped sites, or at sites where land use may change in the future, ICs may be necessary to ensure that the vapor intrusion pathway is effectively addressed in the future. ICs at undeveloped sites could include mechanisms to require PEM in new buildings. Selecting and implementing PEM avoids some of the difficulties associated with attempting to predict the potential for vapor intrusion prior to building construction.

9.5.2 Institutional Controls

For existing vapor intrusion mitigation systems, ICs may be required to ensure that the system is operated, maintained, and monitored. Maintenance and monitoring of the mitigation system, which are discussed in Sections 8.3 and 8.4 of this document, are generally appropriate to ensure that the system is performing as intended. In addition, ICs may provide access to property to conduct routine maintenance and monitoring activities, or separate access agreements should be considered. Additional information regarding ICs is provided in Section 8.6 of this document.

9.5.3 Community Input and Preferences

Community acceptance of early action may vary widely, depending on risk to building occupants and past experiences at the site, including interaction with site stakeholders and regulators and perceptions of the site and its risks or apparent risks. Some owners and occupants may view PEM as a precautionary measure and be willing to have mitigation systems installed; some may even request them before characterization is completed. On the other hand, some home owners may not agree to have a mitigation system installed unless the pathway is demonstrated to be complete.

Others may be reluctant to install mitigation systems because of the operation costs or the inconvenience associated with the installation and subsequent monitoring. Although some owners may view mitigation systems as an advantage when they sell a property, others may be concerned with the possible negative effect on property values.

Issues and concerns about equity and fairness can also arise when some homes within a neighborhood receive mitigation systems and others do not. In some situations, it may be easier to persuade property owners to install vapor intrusion mitigation systems if the entire street, block, or neighborhood is found to warrant early action.

Public meetings and one-on-one meetings provide opportunities to discuss PEM with affected property owners and building occupants and obtain information and input. Section 10.0 of this document provides additional information and guidance about community involvement and engagement.

Figure 9-1a: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Single Building (Rural Setting)

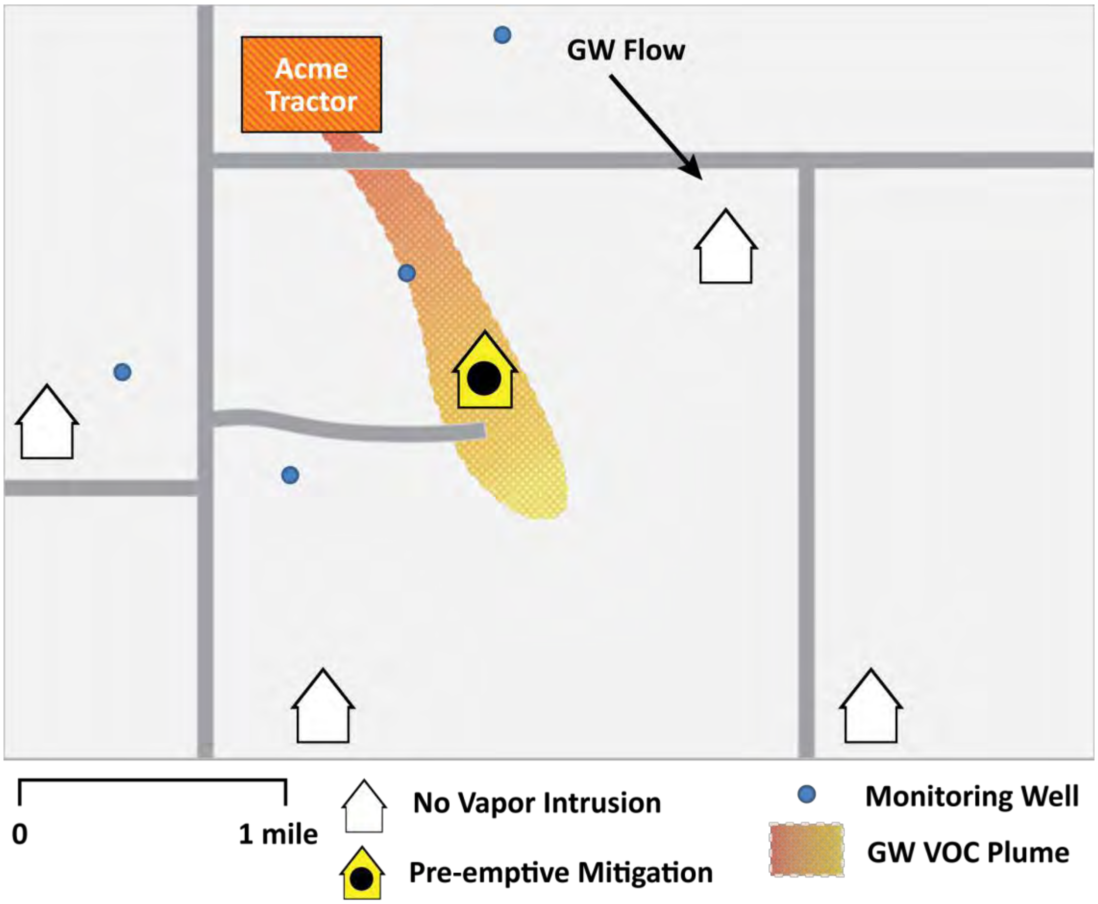


Figure 9-1b: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Single Building (Suburban Setting)

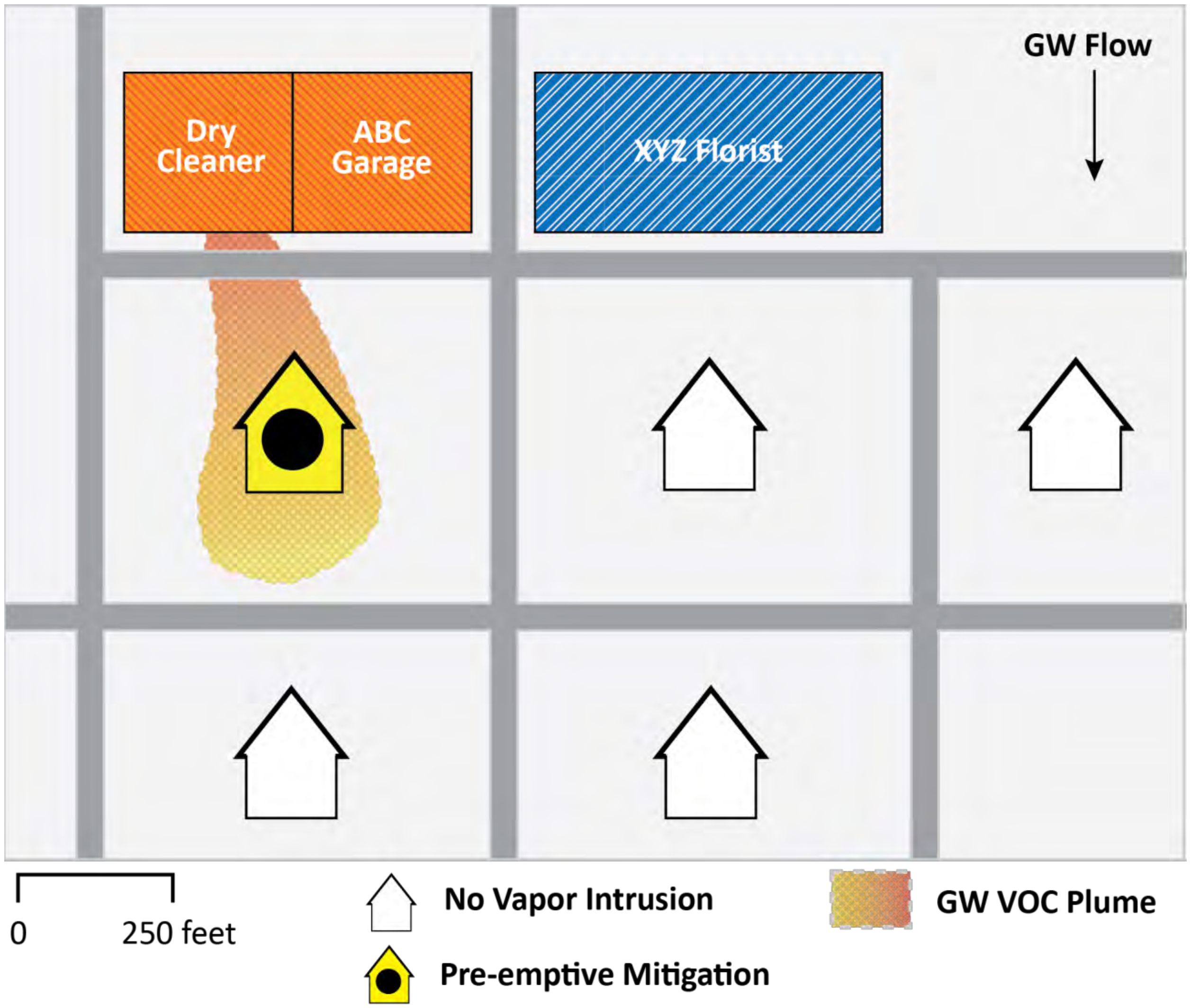


Figure 9-2: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Multiple Buildings, Each with Limited Data

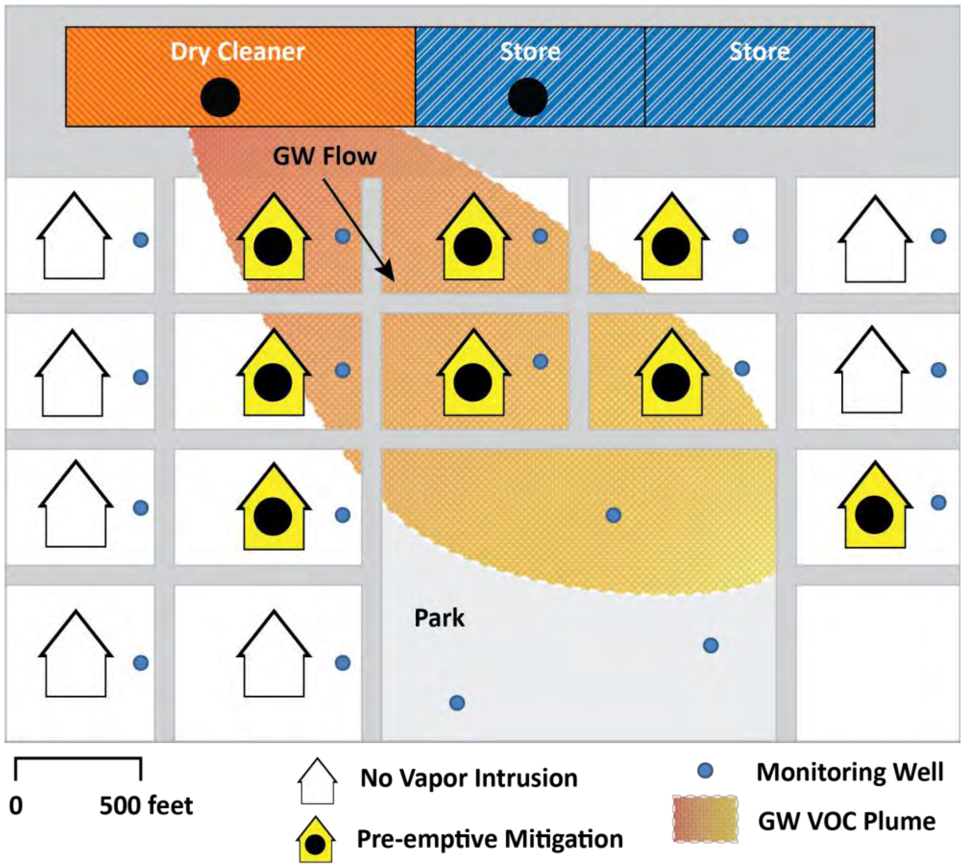
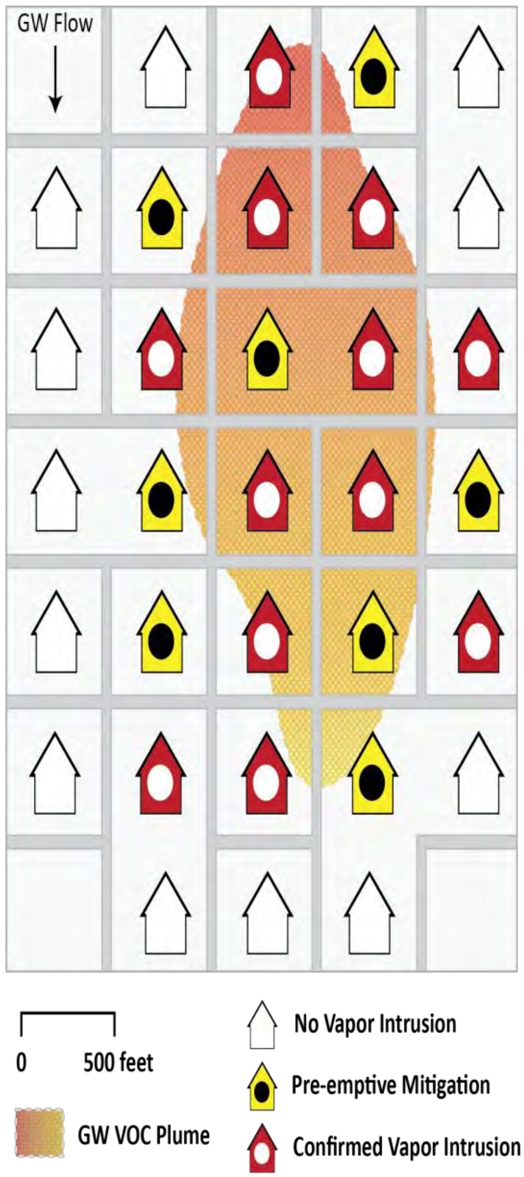


Figure 9-3: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Multiple Buildings, Some with Only Limited or No Data



10.0 PLANNING FOR COMMUNITY INVOLVEMENT

Communicating information about environmental risk is one of the most important responsibilities of risk managers and community decision-makers. Simply stated, risk communication, whether written, verbal, or visual statements concerning risk, is the process of informing people about potential and perceived hazards to their person, property, or community. In discussing risk, it should be put into context. Recognize that there are personal, cultural and societal dimensions of risk. Include advice about risk-reduction behavior and encourage a dialogue between the sender and receiver of the message. The best risk communication occurs in contexts in which the participants are informed about risks they are concerned about, the process is fair, and the participants are free and able to solve whatever communication difficulties arise. *Risk Communication in Action: The Risk Communication Workgroup* (EPA 2007) is one of several resources available that explain the elements of successful risk communication and describe communication tools and techniques.

Thus, community involvement is a key component of any site investigation or other EPA response action. Members of the public affected by environmental contamination should be aware of what EPA is doing in their community and have a say in the decision-making process. Stakeholder and community involvement is particularly important for sites with vapor intrusion issues, in part because the exposure to toxic vapors may pose a significant risk that is unknown to inhabitants (in the absence of mitigation systems), as they potentially arise in homes, workplaces, schools, and places of commerce and gathering. Stakeholder and community involvement should be conducted from the earliest stage of the site assessment and risk assessment process, with on-going education, two-way communication, and discussion throughout the entire process to create community trust and acceptance.

Community involvement activities should be initiated as soon as possible after determining that vapor intrusion may exist at a particular site. Informing the community about vapor intrusion concerns and plans to conduct an assessment, including sampling, can be resource intensive. Because of the intrusive nature of assessment and mitigation, stakeholder involvement is important throughout the process.

Public Participation and Risk Communication

A meaningful community involvement process requires knowledge of effective public participation and risk communication practices. Public participation refers to the full range of activities that EPA uses to engage communities in the Agency's decision-making process. In 2003, EPA updated its Public Involvement Policy.[102] Its foundation includes seven basic steps to support effective public participation:

1) Plan and budget.

2) Identify those to involve.

3) Consider providing assistance.

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[102] EPA Public Involvement Policy (2003): http://www.epa.gov/publicinvolvement/policy2003/index.htm.

4) Provide information.

5) Conduct involvement.

6) Review and use input and provide feedback to the public.

7) Evaluate involvement.

To help implement the steps, EPA developed a series of brochures[103] on effective public participation that outline how to budget for, plan, conduct, and evaluate public participation.

EPA Program-Specific Community Involvement Guidance and Recommendations

CERCLA and other EPA regulations[104] require specific community involvement activities that must occur at certain points throughout the cleanup process. Specifically, in 2005, OSWER published the *Community Involvement Handbook*[105] (EPA 540-K-05-003). The handbook presents legal and policy requirements for Superfund community involvement and includes additional suggestions for involving the community in the Superfund process. In addition, EPA's *Proposed Guidelines for Brownfields Grants* require applicants to describe their plans for involving community-based organizations in site cleanup and reuse decisions.[106] The *Grant Funding Guidelines for State and Tribal Response Programs* for brownfields funding also require programs to establish, at a minimum, "mechanisms and resources to provide meaningful opportunities for public participation."[107] In addition, in 1995, EPA promulgated the *RCRA Expanded Public Participation* rule (60 FR 63417-34, December 11, 1995)[108] which created additional opportunities for public involvement in the permitting process and increased access to permitting information.[109]

At sites with vapor intrusion issues, EPA recommends that the site planning team (i.e., the remedial project manager (RPM) or on-scene coordinator (OSC); community involvement coordinator (CIC); risk assessor; the enforcement case team; EPA contractor; state, tribal, or local agency staff; or others) to consider the following:

- Develop a community involvement plan (CIP) or update the existing CIP.

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[103] http://www.epa.gov/publicinvolvement/brochures/index.htm

[104] 40 CFR §300.155 http://edocket.access.gpo.gov/cfr_2003/julqtr/pdf/40cfr300.155.pdf

[105] EPA *Superfund Community Involvement Handbook*: http://www.epa.gov/superfund/community/cag/pdfs/ci_handbook.pdf

[106] EPA Brownfields Grants website: http://www.epa.gov/brownfields/cleanup_grants.htm

[107] EPA Brownfields State and Tribal Response Program Grants website: http://www.epa.gov/brownfields/state_tribal/fund_guide.htm

[108] Section 7004(b) of the Resource Conservation and Recovery Act provides EPA broad authority to encourage and assist public participation in the development, revision, implementation, and enforcement of any regulation, guideline, or program under RCRA.

[109] EPA *RCRA Public Participation Manual*: http://www.epa.gov/osw/hazard/tsd/permit/pubpart/manual.htm

- Learn about the site and the community to foster development of a CIP that highlights key community needs, concerns and expectations.

- Commit to ongoing, sustained communication activities throughout vapor mitigation and site cleanup efforts.

- Develop a communication strategy[110] and conduct outreach to inform stakeholders about the facts and findings pertaining to the site.

- Obtain written permission, if appropriate and necessary, for building/property access, and involve the property owner/occupant in identifying or removing potential indoor air contamination sources, including inspection of residence and completing an occupant survey.

- Fully communicate and interpret sampling results, and evaluate mitigation options, if applicable.

When considering the most effective community involvement strategies, EPA recommends that its previous involvement be considered, as well as the existence of community or neighborhood groups and the phase of the regulatory process in which vapor intrusion is being addressed. Additional resources for planning and implementing effective community involvement activities are discussed in Section 10.2: Communication Strategies and Conducting Community Outreach.

10.1 Developing a Community Involvement or Public Participation Plan

A CIP is a site-specific strategy to enable meaningful community involvement throughout the cleanup process.[111] CIPs specify EPA-planned community involvement to address community needs, concerns, and expectations that are identified through community interviews and other means. A CIP will enable community members to understand the ways in which they can participate in decision-making throughout the cleanup process. The purpose of the CIP is not to provide technical answers to the community's questions. Rather, the CIP is EPA's plan for informing and involving the community in the cleanup process and can be a powerful way to communicate EPA's commitment to listening and responding to community concerns, and provide timely information and opportunities for community involvement.

The CIP should be a "living" document and is most effective when it is updated or revised as site conditions change. When developing the CIP document, EPA recommends that the site planning team should consider following steps:

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[110] A communication strategy can be one component of a CIP, but it addresses a specific event, issue, or concern, such as an emergency response to a release, or communicating risk at a site. The CIP, on the other hand, describes an overall strategy for conveying information throughout the cleanup process at a site.

[111] *EPA Superfund Community Involvement Toolkit.* 2011. *Community Involvement Plans.* Available at: http://www.epa.gov/superfund/community/pdfs/toolkit/ciplans.pdf

Describe the Environmental Setting and Cleanup Process

Describe the release and affected areas (the site). This includes information about the site, its history, the key issues related to site contamination, and how vapor intrusion fits into EPA's overall cleanup effort at the site.

Describe and Learn about the Community

Describe the community. The community profile is a description of the affected community that summarizes demographic information and identifies significant subgroups in the population, languages spoken, and other important characteristics of the affected community, such as whether the site is located in an area with environmental justice concerns or includes sensitive populations. It also should include information about how the profile was derived.

Learn about community needs, concerns and expectations: Issues of concern to residents and business owners are identified through community interviews, informal discussions and interactions, local media reports, and other insights about the affected community. Questions may include:

- What are public perceptions and opinions of EPA and the cleanup process?
- How do people want to be kept informed (i.e., mechanisms to deliver information)?
- How do people want to be included in the decision-making process?
- What are the perceived barriers to effective public participation?
- Are there other sources of pollution that affect the community?
- Have there been past experiences of mistrust or any unique concerns?

This information can be used to recommend any special services to be provided, including technical assistance, formation of a Community Advisory Group, facilitation/conflict resolution, or translation services.

Write and Compile the CIP

Once the site planning team has learned about the community, it is time to put the information together in a way that will be useful to EPA and the community. In addition to the site description, community description, and community needs and concerns, the CIP also may include a reference listing of contacts (name, address, phone, email) useful for the community or the site planning team. Consider whether permission should be obtained before including contact information for some of the people listed. EPA recommends that the contact list include contact information for:

- The site planning team.

- Community groups and community leaders.
- Local elected officials.
- Local, state, tribal, and federal agency staff relevant to the site.
- Media contacts (including social media outlets and community journalists).
- Others, as appropriate.

To ensure that the CIP is indeed informed by the community, EPA recommends that a draft of the CIP be shared with the community, and their input and feedback be invited along the way. The CIP should offer a clear invitation to the community for feedback before it is finalized. Again, the CIP should be a "living" document and is most effective when it is updated or revised as site conditions change. In some cases, particularly when the CIP is updated or revised for a FYR or where community interest is minimal, a short CIP outlining EPA's plan for community involvement may be all that is needed. For most sites, EPA recommends that the CIP be written to address the community directly, and their active involvement be invited at each stage of the cleanup process.

10.2 Communication Strategies and Conducting Community Outreach

EPA recommends that community outreach activities be initiated as soon as possible after determining that vapor intrusion may exist at a particular site. Informing and educating the community includes distributing information and providing opportunities for EPA to listen to community concerns. Community outreach activities should be tailored to the community based on information gleaned from community interviews and other methods used in developing the CIP. Public health officials from state or local agencies may be helpful in communicating risk information and answering questions from the community.

Communication Strategies

Communication strategies are plans for communicating information related to a specific issue, event, situation, or audience. They serve as the blueprints for communicating with the public, stakeholders, or even colleagues, and should specify the mechanisms that will be used to obtain feedback on the strategy. EPA recommends that communication strategies:

- Outline the objective and goals of the communication.
- Identify stakeholders.
- Define key messages.
- Pinpoint potential communication methods and vehicles for communicating information and obtaining information from the community for a specific purpose.

When developing a communication strategy, the first step is to determine why the communication is necessary and define its desired objectives, and then to focus on defining the audiences and how to reach them. Keep in mind that the demographics, knowledge, and concerns of the audiences play an important role in defining the key messages. Once the key messages are defined, the outreach vehicle can be determined.

Conducting Community Outreach

The site planning team likely will use several different outreach techniques during the course of the cleanup process. When planning community outreach, EPA generally recommends that the site planning team collaborate with internal and external partners, such as local, state, and tribal officials and departments of health; faith-based organizations; and community groups. It is important to accommodate hearing-impaired or limited English proficiency (LEP)[112] persons in all outreach efforts by providing spoken or sign language interpreters at meetings and translating printed outreach materials. It also is important to ensure that the community understands the concept of vapor intrusion.

Examples of community outreach techniques to consider are described below.

Public Meetings/Gatherings

Public meetings are a useful opportunity to explain environmental conditions at the site, potential health impacts, intended indoor air sampling, and remediation strategies. It may be helpful to hold meetings prior to and following key sampling events to describe sampling strategies and consequent results, respectively. EPA recommends that the meeting include a period to address specific questions from the public regarding sampling results or any other specific concerns, as well as visual aids and maps and spoken or sign language interpreters to facilitate the communication and discussion. The use of a CSM, for example, is useful in public meetings to graphically reinforce the messages. It may be helpful to follow up with meeting participants to inquire about the effectiveness of the meeting and whether it met their needs. Other meeting follow-up activities could include responding to requests for information, distributing meeting notes, and creating a mailing list.

Additional opportunities for the site planning team to communicate with the community in a group setting include public availability sessions and public forums or poster sessions at community group meetings or neighborhood board meetings. These options are a more informal way of interacting with community members and they allow a casual "question and answer" or discussion format as compared to the more formal presentation at a public meeting.

Mass Media

The media can be the best means of reaching a large audience quickly. Extending invitations to the media for important meetings, providing opportunities for media questions to be addressed in a timely manner, and recognizing that the media control the content of

[112] Executive Order 13166, *Improving Access to Services for Persons with Limited English Proficiency*, requires federal agencies to examine the services they provide, identify any need for services to those with LEP, and develop and implement a system to provide those services so LEP persons can have meaningful access to them.

their publications all are important considerations when working with the media. The site planning team can work with the Agency's regional site press officer to foster a relationship with the media by sharing the Agency's rationale for its plans and actions. It is appropriate to use the media to publicize a site-related decision, an upcoming meeting, changes in schedule, or changes in activities or expectations. Press releases can be used to inform the media of major site-related milestones.

Fact Sheets

Communities appreciate concise, easy-to-understand, and technically accurate fact sheets on the history of the contamination, chemicals of concern, potential risks, planned cleanup activities, and the vapor intrusion assessment and response actions. Be sure to include who to contact for more information.

Because sites involving vapor intrusion can be complex, it may be useful to include additional information in the fact sheets for home owners and renters, including information about household products that may be potential sources of indoor air contamination, as well as steps that can be taken to minimize these sources. EPA recommends preparing and distributing periodic status updates and fact sheets to concerned community members throughout the cleanup process.

Letters

Whenever there are plans to conduct indoor air sampling, EPA recommends sending a letter to each building owner and renter explaining plans to conduct indoor air sampling and requesting written permission for voluntary access to do so. This letter generally should be in addition to a one-on-one meeting with the building owner or renter to discuss sampling efforts and access agreements in detail (see Section 10.3). EPA also recommends that letters be sent to each building owner and renter to report sampling results in a timely manner (see Section 10.4). These letters and meetings often are part of a larger effort that also includes use of other communication strategies, such as community meetings and in-person visits.

In-person Visits

EPA recommends individual, one-on-one communication with each property owner and renter whenever possible.

- Try to schedule in-person visits with individual property owners and renters. These visits also may include owners and renters of properties located outside the planned investigation area, as applicable. The initial visit can be used to explain sampling plans in more detail, answer questions, and obtain written permission to sample.

- During the visit, the property owner or renter should be briefed about any instructions to follow during sampling activities (for example, keep doors and windows closed during sampling). A general survey of the building should be conducted to determine likely sources of indoor air contaminants.

- The site planning team also should instruct the owners and renters about the sampling devices that will be used, what they look like, where they will be located, and any restrictions to daily activities required as a result of the ongoing sampling activities.

- The site sampling team should arrive on time for the sampling. Someone knowledgeable and able to explain the sampling procedure should accompany the sampling staff. As appropriate, include an interpreter as well.

Information Repository

An information repository can be established and maintained prior to, during, and following site activities and is required for sites where remedial action or removal actions (where on-site action is expected to exceed 120 days) are undertaken pursuant to CERCLA. The information repository should include the administrative record, fact sheets, question-and-answer sheets, and other site-related documents and should be located near the site. However, given the tremendous change in information technology, it may also be appropriate to set up an Internet-based or digital repository (webpages) to share key information. This depends on the community's ability to access and utilize this technology. EPA recommends that community members be made aware of the information repository through the other public outreach mechanisms described above (e.g., local media, newsletters, and public meetings).

Electronic Notification

It also may be useful to establish a registration capability that allows interested community members to sign up for automatic alerts to updates posted on the site website or email listserv.

10.3 Addressing Building Access for Sampling and Mitigation

Gaining access to owner-occupied residences for vapor intrusion sampling and mitigation may be handled differently than for commercial buildings or rental properties. The number of attempts to obtain access to perform a vapor intrusion assessment or install a mitigation system should be consistent with regional practice. In general, more than one attempt for access is recommended. All attempts should be documented using telephone conversation records, emails, or letters sent to home or building owners. EPA recommends that all requests for access, as well as provision of access, be in writing in order to document EPA's due diligence to protect human health at the site. EPA recommends that the site planning team instruct owners or renters about the sampling devices being used, including what they look like, where they will be located and any restrictions to daily activities required due to ongoing sampling.

Owner-Occupied Residences: Allowing EPA to sample or install mitigation systems in an owner-occupied residence is a voluntary action. Owners occupying their homes should be encouraged to take advantage of an offer for an assessment and mitigation system, if necessary.

Rental Properties: Access may be voluntary or involuntary. Site planning teams often deal with both owners and renters when there is a need to sample on, in, or under a rental property. There are different legal and communication issues for owners and renters. For example, the owner is responsible for granting access for sampling and for installation of mitigation measures, if they are necessary; however, if the owner grants access, logistics normally are arranged with the renter. Both the owner and the renter should be apprised of vapor intrusion exposure concerns that have the potential to adversely affect human health, which includes providing sampling results to both parties. If the owner of a rental property refuses access, EPA may require access, in the interest of protecting the occupants, for determining the need for response, choosing a response action, taking a response action, or otherwise enforcing CERCLA or RCRA (EPA 1986, 1987, 2010a).

Nonresidential Buildings: Access may be voluntary or involuntary. Site managers also may need to sample on, in, or under nonresidential buildings, such as schools, libraries, hospitals, hotels, and stores. In these situations, broader outreach to the public may be appropriate in addition to maintaining direct contact with the property owner.

Property Ownership Changes: For owners of homes or buildings who did not provide access for assessment sampling or installation of a mitigation system, EPA recommends that the site planning team make reasonable attempts to track ownership changes, although the appropriate state or local agency or PRP may be in a better position to track this information. For example, reasonable attempts to make contact can be done annually by conducting drive-bys or annual inspections and noting homes or buildings for sale, checking real estate sales listings periodically, or using other mechanisms. Homes that were initially targeted but not sampled can be reconsidered during the review or if there are major changes to the toxicity values for the site contaminants of concern. If ownership changes are noted, appropriate follow-up can be conducted with the new home owner or building owner.

10.4 Communication of Indoor Sampling Efforts and Results

The community involvement plan or public participation plan should pay particular attention to addressing community concerns and participation regarding indoor air and sub-slab sampling. In addition to the general community involvement activities occurring throughout the cleanup process (see Section 10.2), the site planning team may choose to hold a community meeting to discuss indoor sampling efforts and results, and follow up by sending a letter to each home or building owner and renter explaining plans to conduct sampling or providing sampling results. EPA recommends that this letter be in addition to a one-on-one meeting with the building or home owner to discuss access agreements, sampling efforts, and sampling results.

Letters Transmitting Sampling Results

EPA recommends that the site planning team provide validated sampling results in plain English (and translations, if necessary) to property owners and renters within about 30 days of receiving the results. The transmittal letter also should indicate what future actions, if any, are necessary based on the sampling results. Letters reporting sampling results almost certainly will contain site-specific and possibly building-specific information about various issues, such as chemicals of concern, screening levels and mitigation options. However, additional information for inclusion in these letters may include, but is not necessarily limited to:

- Site and Home/Building Information.
  - Site name and location of contamination.

  - Date of sampling.
  - Address of sampled home or building.
  - Locations sampled (both indoor and outdoor).

- Sampling Results
  - Sampling results for chemical(s) of concern.
  - Sampling results for other chemicals, if detected, including an explanation of results believed to be attributable to background sources, if known.
  - Risk-based screening levels used (for example, VISLs described in Section 6.5).
  - Explanation of sampling results, if known.
  - Paragraph listing results, comparison to screening level and explanation.
  - Table of results, including sampling results and screening values, followed by an explanation of results, if known.
  - Simple tabulated and color-coded results (representing exceedances of human health risk levels or no exceedance).

- Diagrams/Illustrations
  - Letters requesting access for sampling may include diagrams and illustrations of sampling devices.
  - Letters giving sampling results or suggesting a mitigation system may include diagrams and illustrations of sampling locations or diagrams of specific mitigation systems (e.g., how a SSD system works and looks).

- Next Steps
  An explanation of what the building owner or resident should expect as a result of the sampling and when he or she can expect to be contacted again. This section may include:
  - Explanation of mitigation process and responsibilities (if applicable).
    -Mitigation options.
    -Timeline for further contact regarding system installation and options.
    If a building mitigation system is recommended on the basis of a risk assessment, EPA recommends that the site planning team explain that the risk calculation reflects many conservative, health-protective factors.

  - EPA recommends that the letter describe actions that property owners and occupants can take to reduce vapor intrusion exposure until mitigation systems are in place.

- Contact information
  - Contact information for a person who can answer questions or supply further explanations should be included in communications with building and homeowners. The location of the site information repository or site website can be included as a resource for public access to more detailed site documents.

10.5 Transmitting Messages Regarding Mitigation Systems

The initial notification to residents or building owners about mitigating vapor intrusion can be delivered in various ways. A primary mechanism is a face-to-face meeting with the building owner or occupant to explain the sampling results and discuss next steps, including installation of a vapor intrusion mitigation system. EPA recommends that this meeting include a member of the site planning team (RPM or OSC and risk assessor, for example), a representative from the local health department or the Agency for Toxic Substances and Disease Registry (ATSDR), and the mitigation contractor scheduler. This meeting could discuss topics such as:

- Sampling Results: Describe where samples were taken and the chemicals of concern, and explain the results as related to site action levels. Any questions related to health impacts or risks can be answered by the risk assessor or health representative at this time.

- Mitigation System Details: Describe the need for a mitigation contractor to visit the residence to identify potential locations for the mitigation system. The property owner will need to be present for the visit and will have input about where the system is installed, if they agree to install such a system. Photos of a mitigation system (piping, system fan, number of holes drilled in the slab, height of the vent on the outside of the residence, etc.) may be helpful. The site planning team representative should also mention the need to sign an additional access agreement approving the installation of the mitigation system described in the meeting.

- Cost of the Mitigation System: Explain which party will pay for installation of the mitigation system (EPA or a PRP, for example) and anticipated property-owner costs. EPA or a PRP may pay for the system installation, and the property owner or PRP may be required to pay for the monthly costs associated with the mitigation system.

- Project Schedule and Next Steps: The meeting may be concluded by giving an overview of the project timeline, including the appointment for the mitigation contractor visit and system installation. The property owner or occupant should be told that the project sample team will need to return after the mitigation system is installed to conduct post mitigation sampling to confirm that the system is lowering the air levels to below site-specific action levels. A follow-up sampling date will be determined and sample results will be communicated to the property owner.

Notification also can be provided through the data transmittal letter. In many cases, however, the decision to install mitigation systems will not have been made prior to the transmittal of sampling results. In these situations, data transmittal letters can convey that EPA is reviewing all data results for the affected area and considering appropriate next steps. Once the decision document is signed, the site planning team can develop and mail a fact sheet to all community members in the affected area, followed by a community meeting.

In addition, if a vapor intrusion mitigation system is installed, EPA recommends that the property owner or renter be informed that the system normally is designed to protect the home or building only against vapor-forming chemicals coming from the subsurface. A vapor intrusion mitigation system generally will not protect the home against continuing indoor sources because vapor intrusion mitigation systems typically are not indoor air filtration systems. For this reason, property owners and occupants should be educated about sources of indoor air contamination in order to minimize their exposures. Further, mitigation systems installed for vapor intrusion will also reduce or prevent naturally occurring radon from entering the building, providing an added benefit to human health.

EPA recommends that current owner-occupants be advised that if they decline an offer to install a vapor mitigation system, they might be responsible for the costs of installing and maintaining their own system if they decide to do so at a later time. The waiver should be documented.

10.6 Addressing Community Involvement at Legacy Sites

Ongoing site activities with assessment components, such as remedial investigations and monitoring, allow EPA to continually evaluate site conditions and adjust cleanup actions as warranted. During periodic reviews or conducting other site activities, such as the FYR required by CERCLA, EPA has evaluated vapor intrusion where appropriate. In some instances, EPA has newly identified vapor intrusion as an exposure pathway. These mature or "legacy" sites present a unique challenge to site planning teams.

Conducting community involvement at legacy sites may be complicated by several factors including:

- A remedy for the control of exposure to volatile organic chemicals already has been installed, proposed, or is under construction as part of the cleanup plan.

- Ownership of properties previously exposed to VOCs has changed hands through resale, foreclosure, or assumption of the property by second-generation homeowners. These owners were not part of any original resolution of exposure issues and in many cases may not be aware that a remediation or treatment was put in place.

- Property owners and other community members who participated in prior cleanup efforts may be reluctant to fully engage with efforts to reopen lines of investigation at their properties.

In these and similar circumstances, the challenge for Agency representatives is to resume contact with communities who have put past difficulties behind them. In many cases, mailing lists are outdated, previous reliable contacts no longer are available, and elected officials may not have institutional memory of the events that prompted the remediation.

Strategies for Revitalizing Community Involvement at Legacy Sites

Every legacy re-entry will be a site-specific situation. Therefore, EPA recommends that events and activities be planned to acknowledge and accommodate the inevitable changes in the makeup of a community. In addition to the communication strategies and community involvement techniques described in Sections 10.1 through 10.5, additional suggestions to ease re-entry and revitalize community involvement at a legacy site include:

- Reassess the community and the site by revisiting the site and the surrounding areas and taking note of new construction.

- Reintroduce yourself and the Agency to current municipal staff and check previously used public venues for viability. Determine if new venues may be closer or more accessible to the community.

- If contacts within the community are still extant, reconnect; ask for updates on the growth and stability of the community. If no viable contacts exist, attempt to cultivate new ones.
- Revise and update mailing lists and fact sheets.

As with all sites affected by vapor intrusion issues, be prepared to meet with property owners door to door and to hold public meetings or forums to explain the current investigation and its importance to ensuring public safety.

10.7 Property Value Concerns for Current and Prospective Property Owners

Property value issues are outside the scope of Agency authority. In general, if asked, EPA recommends that regional staff suggest that prospective buyers and sellers contact real estate professionals and lenders from the local area with questions about property values. If a home owner or renter has questions about vapor intrusion mitigation systems, EPA regions can provide information that explains how vapor intrusion systems are designed to reduce exposure to chemicals found in indoor air and to avert human health-related problems.

10.8 Additional Community Involvement Resources

EPA's Superfund Community Involvement Program:

EPA's Superfund Community Involvement website contains many resources that may be helpful for planning community involvement activities for other cleanup programs. This resource includes a list of regional Superfund community involvement points of contact, a list of technical assistance and training resources, and descriptions and links to community involvement policies, guidance and publications (see http://www.epa.gov/superfund/community/).

EPA's Superfund Community Involvement Toolkit (CI Toolkit):

While targeted to a Superfund Program audience, the CI toolkit may be helpful to a wide variety of users because it is a practical, easy-to-use aid for designing and enhancing community involvement activities and contains tips on how to avoid some of the pitfalls common to the community involvement process. The toolkit enables users to quickly review and adapt a variety of community involvement tools to engage the community during all stages of the cleanup process. Relevant tools include tips for conducting public availability and poster sessions and public meetings, developing fact sheets, working with the media, planning communication strategies, developing a Community Involvement Plan, and establishing an information repository (see http://www.epa.gov/superfund/community/toolkit.htm).

EPA's Community Engagement Initiative:

The OSWER CEI is designed to enhance OSWER and regional offices' engagement with local communities and stakeholders to help them participate meaningfully in government decisions on land cleanup, emergency preparedness and response, and the management of hazardous substances and waste (see http://www.epa.gov/oswer/engagementinitiative/).

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APPENDIX A
CHEMICALS OF POTENTIAL CONCERN FOR VAPOR INTRUSION

This appendix identifies chemicals that meet the criteria for vapor-forming chemicals described in Section 3.1. These criteria do not include a consideration of whether these chemicals are regulated pursuant to CERCLA, as amended, or RCRA, as amended. The list of vapor-forming substances warranting consideration for potential vapor intrusion may be modified in the future as toxicity values are updated.

EPA recommends that the following chemicals be routinely evaluated during vapor intrusion assessments conducted in accordance with the Final VI Guidance, when they are present as subsurface contaminants.

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Acetaldehyde	75-07-0
Acetone	67-64-1
Acetone Cyanohydrin	75-86-5
Acetonitrile	75-05-8
Acrolein	107-02-8
Acrylonitrile	107-13-1
Allyl Chloride	107-05-1
Aroclor 1221	11104-28-2
Aroclor 1232	11141-16-5
Azobenzene	103-33-3
Benzene	71-43-2
Benzyl Chloride	100-44-7
Biphenyl, 1,1'-	92-52-4
Bis(2-chloro-1-methylethyl) ether	108-60-1
Bis(2-chloroethyl)ether	111-44-4
Bis(chloromethyl)ether	542-88-1
Bromo-2-chloroethane, 1-	107-04-0
Bromobenzene	108-86-1
Bromochloromethane	74-97-5
Bromodichloromethane	75-27-4
Bromomethane	74-83-9
Butadiene, 1,3-	106-99-0
Carbon Disulfide	75-15-0
Carbon Tetrachloride	56-23-5
Chloro-1,1-difluoroethane, 1-	75-68-3
Chloro-1,3-butadiene, 2-	126-99-8
Chlorobenzene	108-90-7
Chlorobenzotrifluoride, 4-	98-56-6

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Chlorodifluoromethane	75-45-6
Chloroform	67-66-3
Chloromethane	74-87-3
Chloromethyl Methyl Ether	107-30-2
Chloropicrin	76-06-2
Cumene	98-82-8
Cyanide (CN-)	57-12-5
Cyclohexane	110-82-7
Cyclohexene	110-83-8
Dibromo-3-chloropropane, 1,2-	96-12-8
Dibromochloromethane	124-48-1
Dibromoethane, 1,2-	106-93-4
Dibromomethane (Methylene Bromide)	74-95-3
Dichloro-2-butene, 1,4-	764-41-0
Dichloro-2-butene, cis-1,4-	1476-11-5
Dichloro-2-butene, trans-1,4-	110-57-6
Dichlorobenzene, 1,2-	95-50-1
Dichlorobenzene, 1,4-	106-46-7
Dichlorodifluoromethane	75-71-8
Dichloroethane, 1,1-	75-34-3
Dichloroethane, 1,2-	107-06-2
Dichloroethylene, 1,1-	75-35-4
Dichloroethylene, 1,2-trans-	156-60-5
Dichloropropane, 1,2-	78-87-5
Dichloropropene, 1,3-	542-75-6
Dicyclopentadiene	77-73-6
Difluoroethane, 1,1-	75-37-6
Dihydrosafrole	94-58-6
Diisopropyl Ether	108-20-3
Dimethylvinylchloride	513-37-1
Epichlorohydrin	106-89-8
Epoxybutane, 1,2-	106-88-7
Ethyl Chloride	75-00-3
Ethyl Methacrylate	97-63-2
Ethylbenzene	100-41-4
Ethyleneimine	151-56-4
Ethylene Oxide	75-21-8
Hexamethylene Diisocyanate, 1,6-	822-06-0
Hexane, N-	110-54-3

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Hexanone, 2-	591-78-6
Hydrogen Cyanide	74-90-8
Mercury (elemental)	7439-97-6
Methacrylonitrile	126-98-7
Methyl Acrylate	96-33-3
Methyl Ethyl Ketone (2-Butanone)	78-93-3
Methyl Isobutyl Ketone (4-methyl-2-pentanone)	108-10-1
Methyl Isocyanate	624-83-9
Methyl Methacrylate	80-62-6
Methyl Styrene (Mixed Isomers)	25013-15-4
Methyl tert-Butyl Ether (MTBE)	1634-04-4
Methylene Chloride	75-09-2
Naphthalene	91-20-3
Nitrobenzene	98-95-3
Nitromethane	75-52-5
Nitropropane, 2-	79-46-9
Nitroso-di-N-butylamine, N-	924-16-3
Nonane, n-	111-84-2
Pentane, n-	109-66-0
Phosgene	75-44-5
Propionaldehyde	123-38-6
Propyl benzene	103-65-1
Propylene	115-07-1
Propylene Glycol Dinitrate	6423-43-4
Propylene Oxide	75-56-9
Styrene	100-42-5
Tetrachloroethane, 1,1,1,2-	630-20-6
Tetrachloroethane, 1,1,2,2-	79-34-5
Tetrachloroethylene	127-18-4
Tetrafluoroethane, 1,1,1,2-	811-97-2
Tetrahydrofuran	109-99-9
Toluene	108-88-3
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1
Trichlorobenzene, 1,2,4-	120-82-1
Trichloroethane, 1,1,1-	71-55-6
Trichloroethane, 1,1,2-	79-00-5
Trichloroethylene	79-01-6
Trichlorofluoromethane	75-69-4
Trichloropropane, 1,2,3-	96-18-4

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Trichloropropene, 1,2,3-	96-19-5
Triethylamine	121-44-8
Trimethylbenzene, 1,2,3-	526-73-8
Trimethylbenzene, 1,2,4-	95-63-6
Vinyl Acetate	108-05-4
Vinyl Bromide	593-60-2
Vinyl Chloride	75-01-4
Xylene, p-	106-42-3
Xylene, m-	108-38-3
Xylene, o-	95-47-6
Xylenes	1330-20-7

APPENDIX B
RECOMMENDED SUBSURFACE-TO-INDOOR AIR ATTENUATION FACTORS

B.1.0. INTRODUCTION

This Final VI Guidance includes recommended medium-specific (groundwater, soil gas, and indoor air) Vapor Intrusion Screening Levels (VISLs) that are intended to help identify those sites likely to pose a health concern from vapor intrusion and identify areas or buildings that may warrant further investigation of the vapor intrusion pathway. These VISLs are recommended for use in evaluating the concentrations of vapor-forming chemicals measured in groundwater, "near-source" exterior soil gas, and sub-slab soil gas in residential and non-residential settings where the potential for vapor intrusion is under investigation.

The subsurface VISLs are developed considering a generic conceptual model for vapor intrusion consisting of a groundwater or vadose zone source of vapor-forming chemicals that diffuse upwards through unsaturated soils towards the surface and enter buildings. The underlying assumption for this generic model is that subsurface characteristics will tend to reduce or attenuate vapor concentrations as vapors migrate upward from the source and into structures. Section 6.5.1 describes this conceptual model further. In general, it is recommended that the user consider whether the assumptions underlying the generic conceptual model are applicable at each site. The *Vapor Intrusion Screening Level (VISL) Calculator User's Guide* (EPA 2012c) provides additional information about the technical basis for deriving the VISLs.

Comparison of sampling results to medium-specific VISLs comprises one line of evidence in the multiple-lines-of-evidence approach described in the Final VI Guidance. The subsurface (groundwater and soil gas) VISLs *(C_{VISL})* are calculated using risk-based, screening levels for indoor air ($C_{target,ia}$) and a medium-specific, subsurface-to-indoor air attenuation factor (α_{VI}), as follows:

$$C_{VISL} = \frac{C_{target,ia}}{\alpha_{VI}} \quad \text{Equation 1}$$

The risk-based, indoor air screening levels ($C_{target,ia}$) are calculated according to the guidance provided in Risk Assessment Guidance for Superfund (RAGS) Part F (EPA 2009) as implemented in EPA's Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/). The medium-specific, attenuation factors (α_{VI}) recommended for calculating the subsurface VISLs are derived from information in *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012a).

This appendix describes the technical basis for the selection of the subsurface-to-indoor air attenuation factors (α_{VI}) that are recommended for use in calculating the VISLs for groundwater, sub-slab soil gas, "near-source" exterior soil gas, and crawl space air, according to Equation 1.

B.2.0. DEFINITION AND DESCRIPTION OF ATTENUATION FACTOR

Vapor attenuation refers to the reduction in concentration of vapor-forming chemicals that occurs during vapor migration in the subsurface, coupled with the dilution that can occur when the vapors enter a building and mix with indoor air (Johnson and Ettinger 1991). The aggregate effect of these physical and chemical attenuation mechanisms can be quantified through the use of a subsurface-to-indoor air vapor intrusion attenuation factor (α_{VI}), which is defined as the ratio of the indoor air concentration arising from vapor intrusion ($C_{IA\text{-}VI}$) to the subsurface vapor concentration (C_{sv}) at the source or a depth of interest in the vapor migration pathway (EPA 2012a):

$$\alpha_{VI} = \frac{C_{IA-VI}}{C_{SV}} \quad \text{Equation 2}$$

As defined here, the vapor attenuation factor is an inverse measurement of the overall dilution that occurs as vapors migrate from a point of measurement in the subsurface into a building; i.e., attenuation factor values decrease with increasing dilution of vapor concentration.

Subsurface vapor concentrations (C_{SV}) may be measured directly under a building (often called sub-slab soil gas or just sub-slab), measured exterior to a building at any depth in the unsaturated zone (often called exterior soil gas), or derived from groundwater concentrations by converting the dissolved concentration to a vapor concentration assuming equilibrium conditions (i.e., by multiplying the groundwater concentration by the chemical's dimensionless Henry's law constant for the groundwater temperature *in situ*) (EPA 2001; Appendix D).

Subfloor vapor concentrations may also be measured in building crawl spaces. Although crawl space samples are not strictly subsurface samples, they represent the vapor concentration underlying a building's living space. Thus, crawl space samples may be evaluated in a manner similar to subsurface vapor samples.

B.3.0. RECOMMENDED ATTENUATION FACTORS

This section summarizes the technical basis and rationale for EPA's recommended attenuation factors for groundwater, sub-slab soil gas, exterior soil gas, and crawl space air, as follows:

- Section B.3.1 summarizes EPA's database of empirical attenuation factor values and the results of analyzing that database.
- Section B.3.2 identifies the recommended empirically based attenuation factors for groundwater.
- Section B.3.3 identifies the recommended attenuation factor for sub-slab soil gas and presents a theoretical analysis that supports the selection of the recommended empirically based value.

- Section B.3.4 recommends a generic attenuation factor for exterior soil gas and discusses its basis, justification, and limited applications.
- Section B.3.5 identifies the recommended attenuation factor for crawlspace vapor.
- Section B.3.6 presents a reliability analysis of the recommended generic attenuation factors.

B.3.1 EPA'S VAPOR INTRUSION DATABASE (EPA 2012A)

The information in *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012a) is used to derive recommended attenuation factor values for use in evaluating subsurface sample concentrations collected as part of vapor intrusion investigations. EPA's vapor intrusion database consists of numerous pairings of concentrations in indoor air and subsurface samples (groundwater, sub-slab soil gas, exterior soil gas, and crawlspace vapor) from actual sites. It represents the most comprehensive compilation of vapor intrusion data for chlorinated hydrocarbons (CHCs) available at this time.

EPA's vapor intrusion database was analyzed and screened to reduce the impacts of background sources to indoor air concentrations. The resulting data distributions are considered representative of vapor intrusion of CHCs from subsurface sources into residential buildings for most conditions. These distributions serve as the basis for identifying the high-end (conservative) attenuation factors for those media.

Table B-1 and Figure B-1 (Table 19 and Figure 34, respectively, in EPA (2012a)) present and compare the distributions of the attenuation factors (groundwater, exterior soil gas, sub-slab soil gas, and crawl space) that remain after applying the respective source strength and indoor air screens considered most effective at reducing the influence of background contributions to indoor air concentrations. These data demonstrate that the attenuation factor distributions obtained for groundwater, sub-slab soil gas, and crawl spaces for multiple buildings and sites are consistent with the conceptual model for vapor intrusion, which predicts that greater attenuation is expected with greater depths to the vapor sources or vapor samples. As shown in Table B-1 and Figure B-1, the paired groundwater–indoor air data generally exhibit greater attenuation (lower attenuation factors) than the paired sub-slab soil gas–indoor air data, which in turn exhibit greater attenuation than the paired crawl space-indoor air data.

B.3.2 RECOMMENDED ATTENUATION FACTORS FOR GROUNDWATER

To account for the inherent temporal and spatial variability in indoor air and subsurface vapor concentrations, the 95th percentile value of the "source-screened" groundwater data subset in EPA 2012a is recommended as a reasonably conservative generic attenuation factor. **Thus, for groundwater, the recommended generic attenuation factor (α_{gw}) is 0.001.** This value is considered to apply for any soil type in the vadose zone (excepting where preferential vapor pathways are present) in cases where the groundwater is greater than five feet below the ground surface. If the depth to groundwater is less than five feet below the building foundation, investigation of the indoor space is recommended, as there is potential for contaminated groundwater to contact the building foundation, either because the capillary fringe intersects the building foundation or groundwater fluctuations results in groundwater wetting the foundation.

Table B-2 (Table 13 in EPA (2012a)) provides statistics and Figure B-2 (Figure 28 in EPA (2012a)) shows box-and-whisker plots for individual sites compared with the statistics for the combined set of screened groundwater attenuation factors. This table and figure show that the 95^{th} percentile value of the combined groundwater-indoor air measurements is considered appropriate for estimating reasonable worse-case indoor air concentrations that might be observed at a site due to vapor intrusion. The majority of sites and buildings would be expected to exhibit lower indoor air concentrations.

A factor that commonly results in greater attenuation (lower attenuation factors) is the presence of laterally extensive, unfractured fine-grained sediment in the vadose zone. Table B-3 (Table 14 in EPA (2012a)) provides selected statistics and Figure B-3 (Figure 29 in EPA (2012a)) shows the box-and-whisker plots for the groundwater attenuation factors for three soil types. Comparing each descriptive statistic (except for the 25th percentile values) indicates that the attenuation factor values for residences overlying soils classified as “very coarse” generally are larger than those for residences overlying soils classified as “coarse,” which are larger than those for soils classified as “fine.” This pattern is consistent with the conceptual model for vapor intrusion; smaller attenuation factors, which indicate greater reduction in vapor concentration, would be expected in vadose zones with finer-grained soils, when all other factors (e.g., depth to groundwater, biodegradability of the volatile chemicals) are the same. The 95^{th} percentile value of the coarse-grained soil is equal to the generic value, as expected, since coarse-grained soil provide low resistance to vapor transport and thus would be expected to yield high-valued attenuation factors. Where fine-grained sediments underlay buildings, however, more attenuation is expected and observed in the database. **Thus, a semi-site-specific attenuation factor of 0.0005 may be used at sites where laterally extensive fine-grained sediment has been demonstrated through site-specific sampling to underlay buildings being investigated for vapor intrusion**.

B.3.3 RECOMMENDED GENERIC ATTENUATION FACTOR FOR SUB-SLAB SOIL GAS

To account for the inherent temporal and spatial variability in indoor air and subsurface vapor concentrations, the 95^{th} percentile value of the “source-screened” sub-slab data subset in EPA (2012a) is recommended as a reasonably conservative generic attenuation factor. Thus, **for sub-slab soil gas, the recommended generic attenuation factor (α_{gw}) is 0.03.**

The selection of this value can be supported by theoretical analysis. Specifically, a simple mass balance analysis, assuming a well-mixed interior volume and steady-state conditions, indicates that the theoretical (true) sub-slab soil gas attenuation factor can be expressed as the ratio of the soil gas entry rate to the building ventilation rate (Song et al., 2011; EPA 2012a) for cases where there is no background contribution to the indoor air concentration. Using median values for residential building volume and air exchange rate (395 m^3 and 0.45 ACH, respectively) provided in the *Exposure Factors Handbook 2011 Edition* (EPA, 2011) and a mid-range value of 5 L/min for soil gas entry rate in sandy materials (EPA 2002, Appendix G), the central tendency value of the sub-slab soil gas attenuation factor (according to Equation 4a), is expected to be approximately 0.002. Using upper-end (10th percentile) values for residential building volume and air exchange rate (154 m^3 and 0.18 ACH, respectively (EPA 2011)) and soil gas entry rate (10 L/min), an upper-end value of 0.02 for the sub-slab soil gas attenuation factor is obtained. These values agree well with the 95th percentile and 50th percentile (median) values (0.03 and 0.003, respectively) obtained from the source-screened data. These calculations buttress the conclusion that the sub-slab attenuation factor distributions summarized in EPA's vapor intrusion database report can be considered representative of vapor intrusion of CHCs into residential buildings for most conditions.

Table B-4 (Table 10 in EPA (2012a)) provides statistics and Figure B-4 (Figure 25 in EPA (2012a)) shows box-and-whisker plots for individual sites compared with the statistics for the combined set of screened sub-slab attenuation factors. This table and figure show that the 95th percentile value of the combined sub-slab-indoor air measurements is considered appropriate for estimating reasonable worse-case indoor air concentrations that might be observed at a site due to vapor intrusion. The majority of sites and buildings would be expected to exhibit lower indoor air concentrations.

B.3.4 RECOMMENDED ATTENUATION FACTOR FOR "NEAR-SOURCE" EXTERIOR SOIL GAS

Based upon the conceptual model for vapor intrusion, the attenuation factors for exterior soil gas data would be expected to be less than those for sub-slab soil gas, because the former includes an additional contribution from attenuation through the vadose zone, and greater than those for groundwater vapors for a given building at a site where groundwater is the primary subsurface source of vapors. The distributions of exterior soil gas attenuation factors shown in Table B-1 and Figure B-1 do not exhibit this expected relationship. In addition, a comparison of exterior soil gas to sub-slab soil gas concentrations for buildings where both types of samples were collected, shown in Figure B-5 (see Figure 6 in EPA (2012a)), suggests that a substantial proportion of the exterior soil gas data in the database, particularly shallow soil gas data, may not be representative of soil gas concentrations directly underneath a building. On this basis, shallow exterior soil gas sampling data generally are not recommended for purposes of estimating indoor air concentrations and the exterior soil gas attenuation factors in Table B-1 are not recommended for use in deriving generic attenuation factors.

Based upon the data in Figure B-5, "deep" exterior soil gas data appear to more reliably reflect sub-slab concentrations beneath buildings. On this basis, "near-source" soil gas sampling data (i.e., collected in the vadose zone immediately above each vapor source) generally are allowed for purposes of estimating indoor air concentrations. However, the same conservative attenuation factor value for sub-slab soil gas is recommended for use with "near-source" exterior soil gas data for this purpose. **Thus, for "near-source" exterior soil gas, the recommended generic attenuation factor is 0.03**.

B.3.5 RECOMMENDED ATTENUATION FACTOR FOR CRAWLSPACE VAPOR

The distribution of attenuation factors presented in Figure B-1 show that attenuation between building crawlspaces and living spaces is limited. To account for the inherent temporal and spatial variability in indoor air and crawlspace vapor concentrations, the 95th percentile value of the "indoor air-screened" crawlspace data subset in EPA (2012a) is recommended as a reasonably conservative generic attenuation factor. **Thus, for crawl space vapor the recommended generic attenuation factor is 1.0** (0.9 rounded up to 1.0).

B.3.6 RELIABILITY ANALYSIS OF THE RECOMMENDED SUBSURFACE-TO-INDOOR AIR GENERIC ATTENUATION FACTORS

An analysis was performed to determine the reliability of these recommended attenuation factors for screening in residences in EPA's vapor intrusion data base with measured indoor air concentrations exceeding target levels corresponding to a cancer risk of 10^{-6} and a hazard quotient of 1. The reliability analysis was performed separately for each medium by determining the number of correct assessments and the number of false negatives for a range of attenuation factors.

For the purposes of this analysis:

- A correct assessment is deemed to occur either: (1) when a chemical's measured indoor air concentration exceeds the target level and the measured subsurface vapor concentration also exceeds the appropriate medium-specific VISL calculated using the specified generic attenuation factor, or (2) when a chemical's measured indoor air concentration is below the target level and the measured subsurface vapor concentration also is below the appropriate medium-specific VISL calculated using the recommended generic attenuation factor. Correct assessments in this analysis represent a correct decision based on subsurface concentration data regarding the potential for vapor intrusion to pose indoor air concentrations that exceed target risk-based concentrations in affected buildings.

- A false negative is deemed to occur when a chemical's measured indoor air concentration exceeds the target level, but the measured subsurface vapor concentration does not exceed the appropriate medium-specific VISL calculated using the specified generic attenuation factor. False negatives in this analysis represent the potential for making an incorrect decision based on subsurface concentration data regarding the potential for vapor intrusion to pose indoor air concentrations that exceed target risk-based concentrations in affected buildings.

This assessment uses the Data Consistency Subset of the EPA's vapor intrusion database for residential buildings (i.e., before screening to minimize the impacts of background contributions to indoor air as described in EPA (2012a)). This subset was chosen to allow for the possibility that background indoor air contributions were incorrectly identified and removed from further analysis in the "source-screened" data subsets presented in EPA (2012a). Thus, false negatives may appear if indoor or ambient (outdoor) sources of VOCs are present and they exceed the indoor air target level. This choice of datasets provides a conservative estimate of the frequency of false negatives identified by this reliability analysis. Even lower rates of false negatives would be obtained when considering the "source-screened" data subsets, described in EPA (2012a), in which the impacts of background contributions to indoor air are minimized.

The results of this assessment are shown in Figures B-6 through B-8 for sub-slab soil gas, groundwater, and exterior soil gas. The essential results are as follows:

- The recommended generic attenuation factors yield low rates of false negatives (< 2%) for all three media when individual pairs of samples are evaluated together.

- The recommended generic attenuation factors for groundwater, exterior soil gas, and sub-slab soil gas provide generally high rates of correct assessments when individual pairs of samples are evaluated together: 78% for groundwater; 76% for exterior soil gas; and 87% for sub-slab soil gas. Higher rates of correct assessments are expected for sub-slab soil gas than for the other subsurface media, likely due to the closer spatial correspondence of building sub-slab soil gas and indoor air samples.

- The rates of correct assessments appear to level off in Figure B-6 through B-8 at about the point on the x-axis where the recommended generic attenuation factors occur.

Significantly higher rates of a correct assessment are reasonably anticipated to be realized by following the Final VI Guidance. Specifically, collecting multiple samples to characterize spatial and temporal variability, collecting multiple lines of additional evidence, and weighing this information together should significantly reduce the "error rates" estimated in this reliability analysis, which are based upon comparison of individual pairs of indoor air and subsurface sample concentrations.

As previously stated, the Final VI Guidance includes subsurface VISLs that are intended to help identify those sites with the potential to pose a vapor intrusion concern. The reliability analysis described above suggests the recommended attenuation factors, on which the recommended VISLs are based, should provide a reasonably small probability of 'screening out' sites that pose a vapor intrusion concern and a high probability of correctly identifying sites or buildings that may pose a vapor intrusion concern.

B.4.0. CONSIDERATIONS FOR NON-RESIDENTIAL BUILDINGS

The recommended attenuation factors (see Sections B.3.2 through B.3.5) are proposed for use for non-residential buildings as well as residential buildings. The rationale is two-fold:

- In many geographic locations, some commercial enterprises have been established in converted residential buildings. Although used for commercial purposes, such buildings can reasonably be expected to exhibit similar susceptibility to vapor intrusion and similar interior mixing and dilution (and, hence, similar attenuation factors) as residential buildings represented in EPA's vapor intrusion database.

- There is currently only limited empirical data for purposes of deriving attenuation factors for the many types of non-residential buildings, other than converted residences, which are expected to exhibit a wide range of attenuation factors. In particular, there is limited empirical data pertaining to soil gas entry rates for conventional commercial or industrial buildings.

There are theoretical considerations to support expectations that larger non-residential buildings that are constructed on thick slabs will have lower attenuation factors than residential buildings. These considerations include:

- Given that the size (e.g., interior height and footprint area) and air exchange rate tend to be larger for many non-residential buildings (see, for example, Table B-5), it is expected that building ventilation rates for many non-residential buildings would be higher than those for residential buildings. A higher ventilation rate is expected to result in greater overall vapor dilution as vapors migrate from a subsurface source into a building. On this basis, many non-residential buildings would be expected to have lower attenuation factors than those for residential buildings, all else being equal.

- Comparing buildings with slab-on-grade construction, non-residential buildings tend to have thicker slabs than residential buildings. With thicker slabs, a given amount of differential settling would be expected to lead to less cracking in the slab and would be less likely to create cracks that extend across the entire slab thickness. Buildings with thicker slabs would, therefore, be expected to exhibit lower soil gas entry rates, all else being equal.

Where appropriate, EPA may consider appropriate building-specific data, information, and analysis when evaluating vapor intrusion into large non-residential buildings.

B.5.0. CITATIONS

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TABLE B 1.
DESCRIPTIVE STATISTICS SUMMARIZING ATTENUATION FACTOR DISTRIBUTIONS FOR GROUNDWATER, EXTERIOR SOIL GAS, SUB SLAB SOIL GAS, AND CRAWL SPACE VAPOR AFTER APPLICATION OF THE DATABASE SCREENS CONSIDERED MOST EFFECTIVE AT MINIMIZING THE INFLUENCE OF BACKGROUND SOURCES ON INDOOR AIR CONCENTRATIONS.

Statistic	Groundwater (GW > 1,000X Bkgd)	Exterior Soil Gas (SG > 50X Bkgd)	Sub-slab Soil Gas (SS > 50X Bkgd)	Crawl Space (IA > Bkgd)
Min	1.0E-07	5.0E-06	2.5E-05	5.7E-02
5%	3.6E-06	7.6E-05	3.2E-04	1.0E-01
25%	2.3E-05	6.0E-04	1.5E-03	2.2E-01
50%	7.4E-05	3.8E-03	2.7E-03	3.9E-01
75%	2.0E-04	2.7E-02	6.8E-03	6.9E-01
95%	1.2E-03	2.5E-01	2.6E-02	9.0E-01
Max	2.1E-02	1.3E+00	9.4E-01	9.2E-01
Mean	2.8E-04	5.0E-02	9.2E-03	4.6E-01
StdDev	1.0E-03	1.7E-01	5.0E-02	2.8E-01
95UCL	3.4E-04	7.8E-02	1.3E-02	5.3E-01
Count All	774	106	431	41
Count >RL	743	106	411	41
Count <RL	31	0	20	0
No. of sites	24	11	12	4

Note: The applied database screens are groundwater (vapor) concentrations > 1,000X “background,” exterior soil gas > 50X “background,” sub-slab soil gas > 50X “background,” and for crawl space, indoor air concentrations > 1X “background.” SOURCE: Table 19 in EPA (2012a).

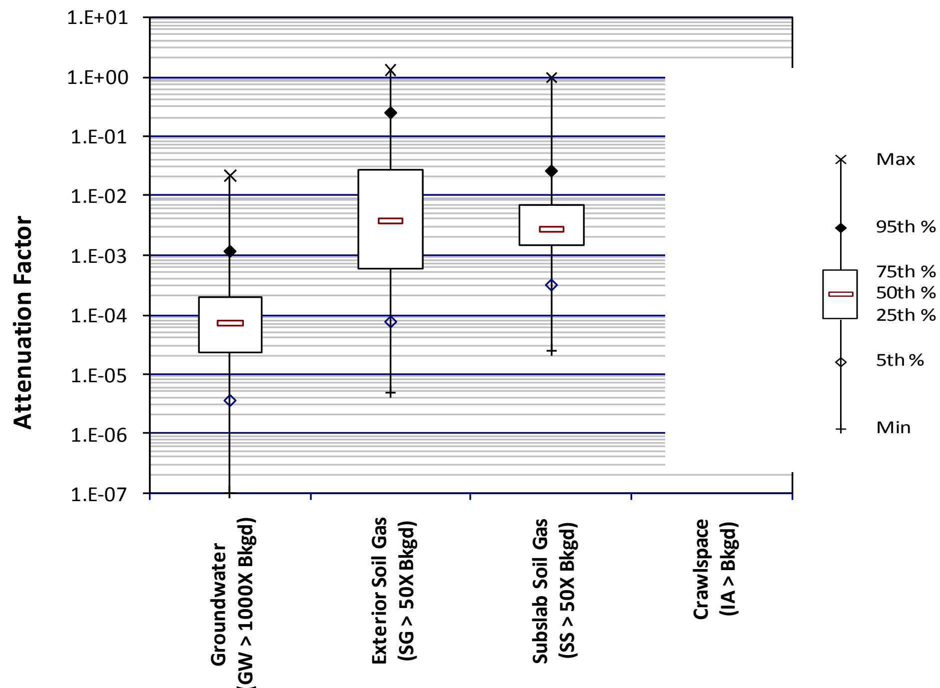

Figure B-1. Box-and-whisker plots summarizing attenuation factor distributions for groundwater, exterior soil gas, sub-slab soil gas, and crawl space vapor after application of the database screens considered most effective at minimizing the influence of background sources on indoor air concentrations. SOURCE: Figure 34 in EPA (2012a).

TABLE B 2.
DESCRIPTIVE STATISTICS SUMMARIZING GROUNDWATER ATTENUATION FACTOR DISTRIBUTIONS FOR INDIVIDUAL SITES COMPARED WITH THE COMBINED DATA SET AFTER SOURCE STRENGTH SCREEN (GROUNDWATER VAPOR CONCENTRATIONS > 1,000 TIMES BACKGROUND”).

Statistic	GW > 1,000 X Bkgd	Allepo	Alliant	BillingsPCE	CDOT	Davis	Eau Claire	Endicott	Grants	Hamilton-Sundstrand	Harcros/Tri State	Hopewell Precision	Jackson	LAFB	Lockwood	MADEP 1	MADEP 2	Moffet	Mountain View	Rapid City	Redfield	SCM - Cortlandville	Uncasville	Wall	West Side Corp.
Min	1.0E-07	9.1E-06	2.5E-06	1.0E-06	1.8E-06	4.7E-05	3.6E-06	1.9E-05	1.0E-07	9.6E-06	1.2E-06	2.5E-05		2.9E-06	8.6E-07	1.6E-04		1.3E-06	4.8E-07	9.9E-06	1.7E-06	5.9E-05	3.3E-05	1.4E-06	2.1E-06
5%	3.6E-06			1.1E-05	3.4E-06			2.8E-05	9.7E-07	1.2E-05		1.7E-04		4.0E-06	2.9E-06						7.6E-06	5.9E-05		1.7E-05	1.3E-05
25%	2.3E-05			2.1E-05	9.9E-06			2.8E-05	2.7E-06	5.8E-05		2.9E-04		1.7E-05	1.9E-05						2.8E-05	5.9E-05	3.5E-04	2.9E-05	1.5E-05
50%	7.4E-05		3.7E-06	3.9E-05	2.2E-05		2.5E-04	1.7E-04	1.2E-05	1.0E-04	2.5E-04	5.6E-04	4.7E-04	3.4E-05	8.8E-05		4.0E-05	4.0E-06	3.3E-06	3.1E-05	7.3E-05	3.1E-04	4.8E-04	8.2E-05	3.7E-05
75%	2.0E-04			8.9E-05	1.5E-04			7.0E-04	8.7E-05	1.5E-04		1.2E-03		1.4E-04	2.7E-04						1.5E-04	1.7E-03	6.5E-04	3.2E-04	2.7E-04
95%	1.2E-03			6.8E-04	5.4E-04			1.4E-03	2.9E-04	2.9E-04		7.7E-03		6.8E-04	1.3E-03						4.8E-04	4.2E-03		1.4E-03	4.3E-03
Max	2.1E-02	1.4E-05	1.1E-03	8.0E-04	5.4E-04	4.3E-04	1.9E-03	1.5E-03	2.9E-04	5.2E-04	3.7E-03	7.7E-03		2.3E-03	2.4E-03	1.0E-03		1.9E-05	3.3E-05	4.0E-05	1.8E-03	6.6E-03	1.8E-03	1.1E-02	2.1E-02
Mean	2.8E-04		1.1E-04	1.2E-04	1.1E-04	2.4E-04	7.7E-04	4.3E-04	7.5E-05	1.2E-04	7.1E-04	1.2E-03		1.6E-04	2.6E-04	6.0E-04		7.9E-06	9.7E-06	2.7E-05	1.3E-04	1.1E-03	6.0E-04	4.9E-04	1.1E-03
StdDev	1.0E-03		3.4E-04	2.1E-04	1.7E-04		8.1E-04	4.8E-04	1.1E-04	9.8E-05	1.3E-03	1.8E-03		3.6E-04	4.5E-04			9.3E-06	1.4E-05	1.6E-05	1.9E-04	1.6E-03	5.1E-04	1.7E-03	4.0E-03
95UCL	3.4E-04		2.8E-04	1.9E-04	1.8E-04		1.4E-03	5.7E-04	1.2E-04	1.5E-04	1.7E-03	2.0E-03		2.2E-04	3.5E-04			2.4E-05	2.3E-05	5.4E-05	1.5E-04	1.6E-03	9.2E-04	9.2E-04	2.3E-03
Count All	774	2	12	25	17	2	6	32	14	32	7	17	1	93	63	2	1	3	5	3	329	28	9	43	28
Count >RL	743	1	5	25	17	2	6	22	14	32	7	17	1	93	63	2	1	3	5	3	329	21	9	43	22
Count <RL	31	1	7	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	6

SOURCE: Table 13 in EPA (2012a).

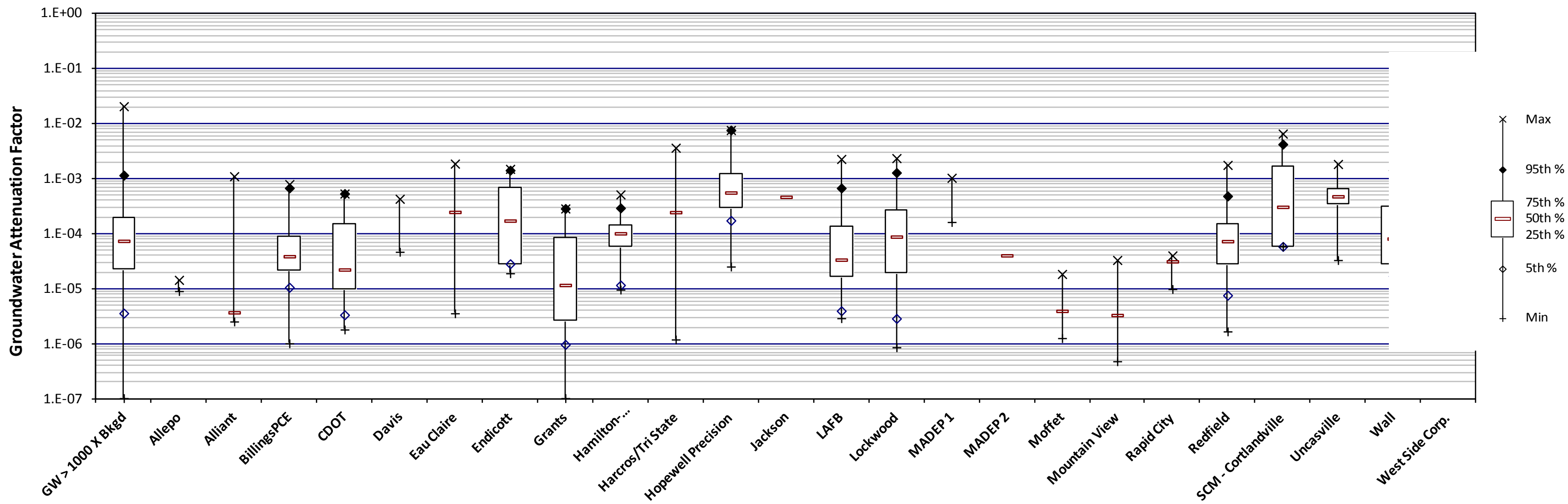

Figure B-2. Box-and-whisker plots summarizing groundwater attenuation factor distributions for individual sites compared with the combined data set after Source Strength Screen (groundwater vapor concentrations > 1,000 times "background"). SOURCE: Figure 28 in EPA (2012a).

TABLE B 3.
DESCRIPTIVE STATISTICS SUMMARIZING GROUNDWATER ATTENUATION FACTOR DISTRIBUTIONS FOR SPECIFIC SOIL TYPES AFTER SOURCE STRENGTH SCREEN.

	Soil Type Below Foundation		
Statistic	**Fine**	**Coarse**	**V.Coarse**
Min	1.0E-07	4.8E-07	2.1E-06
5%	2.3E-06	7.6E-06	1.3E-05
25%	1.9E-05	3.1E-05	2.0E-05
50%	4.6E-05	1.0E-04	1.5E-04
75%	1.4E-04	2.5E-04	6.8E-04
95%	4.5E-04	1.4E-03	4.2E-03
Max	2.4E-03	1.1E-02	2.1E-02
Mean	1.3E-04	3.3E-04	9.7E-04
StdDev	2.4E-04	8.9E-04	3.0E-03
95UCL	1.5E-04	4.1E-04	1.7E-03
Count All	353	369	52
Count >RL	344	359	40
Count <RL	9	10	12
No. of sites	10	15	3

SOURCE: Table 14 in EPA (2012a).

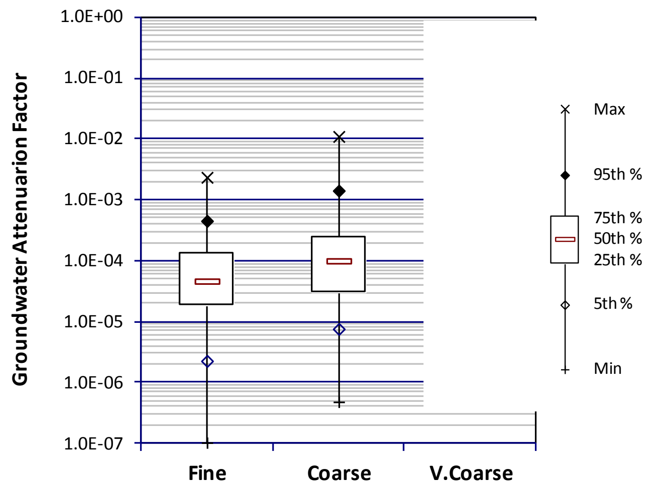

Figure B-3. Box-and-whisker plots summarizing groundwater attenuation factor distributions for specific soil types after Source Strength Screen. SOURCE: Figure 29 in EPA (2012a).

TABLE B 4.
DESCRIPTIVE STATISTICS SUMMARIZING SUB SLAB ATTENUATION FACTOR DISTRIBUTIONS FOR INDIVIDUAL SITES COMPARED WITH THE COMBINED DATA SET AFTER SOURCE STRENGTH SCREEN (SUB SLAB SOIL GAS CONCENTRATIONS > 50 TIMES "BACKGROUND").

Statistic	SS > 50X Bkgd	BillingsPCE	DenverPCEBB	Endicott	Georgetown	Harcros/Tri State	Hopewell Precision	Jackson	LAFB	Orion Park	Raymark	SCM-Cortlandville	West Side Corporation
Min	2.5E-05	2.5E-05	1.1E-03	2.6E-04	1.3E-03	3.8E-04	1.5E-03		3.5E-05	5.0E-04	2.5E-04	3.4E-03	2.0E-04
5%	3.2E-04	9.6E-05		6.9E-04			1.9E-03		1.4E-04		1.2E-03	3.6E-03	
25%	1.5E-03	4.6E-04		1.7E-03			5.0E-03		4.1E-04	1.8E-03	2.0E-03	7.1E-03	5.9E-04
50%	2.7E-03	7.0E-04	6.4E-03	2.6E-03	1.9E-03	4.5E-04	1.0E-02	8.4E-03	1.9E-03	2.8E-03	5.5E-03	1.8E-02	1.5E-03
75%	6.8E-03	1.5E-03		5.0E-03			1.8E-02		5.3E-03	8.8E-03	8.3E-03	4.1E-02	9.7E-03
95%	2.6E-02	2.6E-03		1.1E-02			3.4E-02		3.2E-02		2.1E-02	1.5E-01	
Max	9.4E-01	2.7E-03	4.1E-02	9.4E-01	2.9E-03	2.7E-03	3.4E-02		4.2E-02	3.3E-02	7.9E-02	1.5E-01	3.5E-01
Mean	9.2E-03	9.5E-04	1.7E-02	8.5E-03	2.0E-03	1.0E-03	1.3E-02	8.4E-03	5.0E-03	7.6E-03	7.4E-03	4.1E-02	4.3E-02
StdDev	5.0E-02	7.7E-04	1.9E-02	6.5E-02	8.4E-04	1.1E-03	1.0E-02		9.0E-03	1.1E-02	1.0E-02	5.0E-02	1.2E-01
95UCL	1.3E-02	1.2E-03	3.5E-02	1.6E-02	3.5E-03	2.3E-03	1.7E-02		7.1E-03	1.4E-02	9.2E-03	6.8E-02	1.2E-01
No. of AFs	431	27	5	207	3	4	19	1	52	9	83	12	9
No. of AFs > RL	411	27	5	188	3	4	19	1	52	9	83	12	8
No. of AFs < RL	20	0	0	19	0	0	0	0	0	0	0	0	1

SOURCE: Table 10 in EPA (2012a).

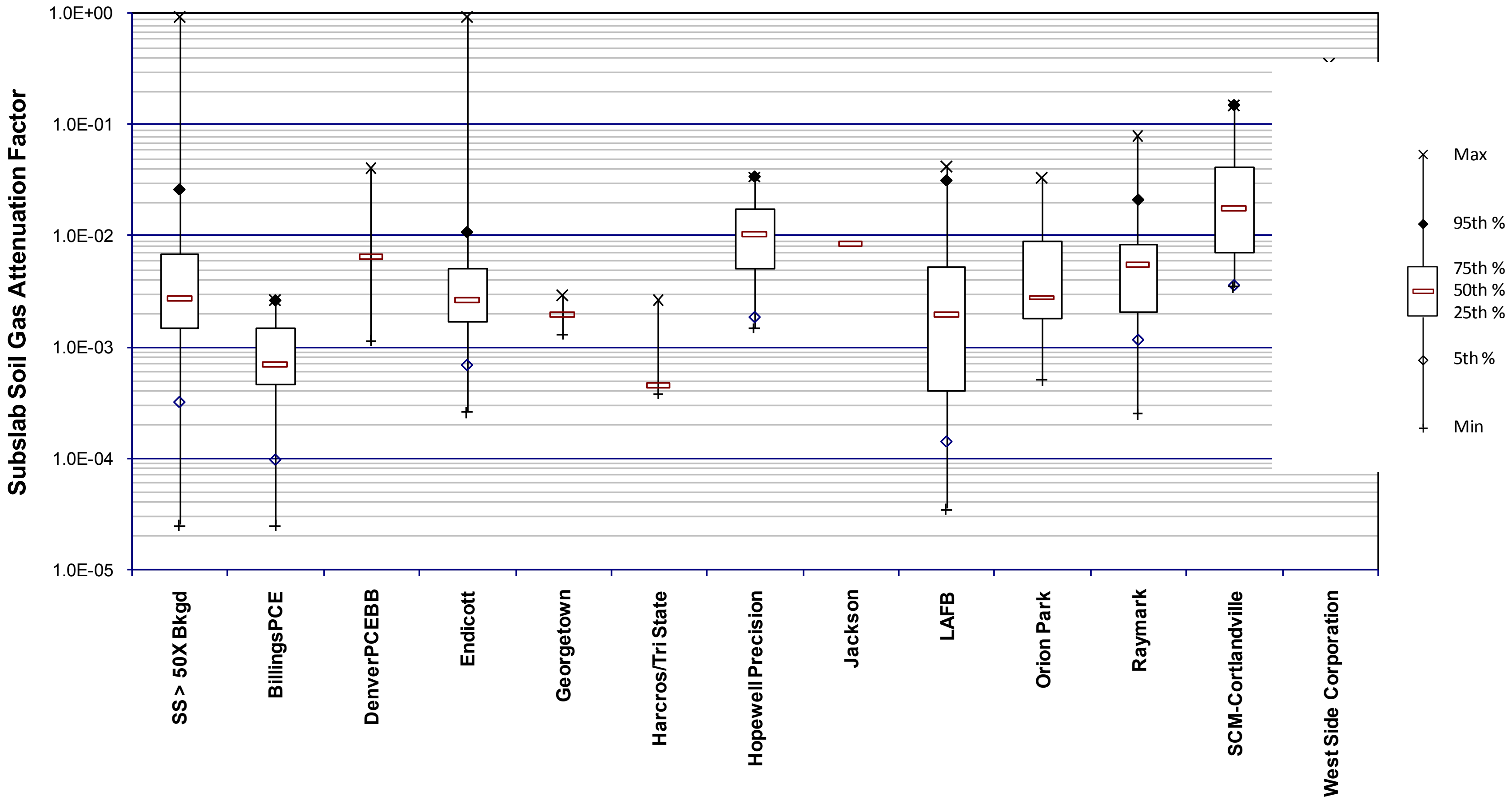

Figure B-4. Box-and-whisker plots summarizing sub-slab soil gas attenuation factor distributions for individual sites after Source Strength Screen (sub-slab soil gas concentrations > 50 times "background"). SOURCE: Figure 25 in EPA (2012a).

TABLE B 5

COMPARISON OF SIZE CHARACTERISTICS FOR RESIDENTIAL AND SOME COMMERCIAL BUILDINGS

Building Parameter and Units	Value and Source for Residential Building	Value and Source for Commercial Buildings, Other Than Warehouses and Enclosed Malls
ACH_{Bldg} (1/hr), 10th percentile	0.18 (EPA 2011, Table 19-1)	0.6 (EPA 2011, Table 19-27)
H_{Bldg} (feet)	8-feet ceiling height (EPA 2011, assumed value)	12-feet ceiling height (EPA 2011, assumed value)

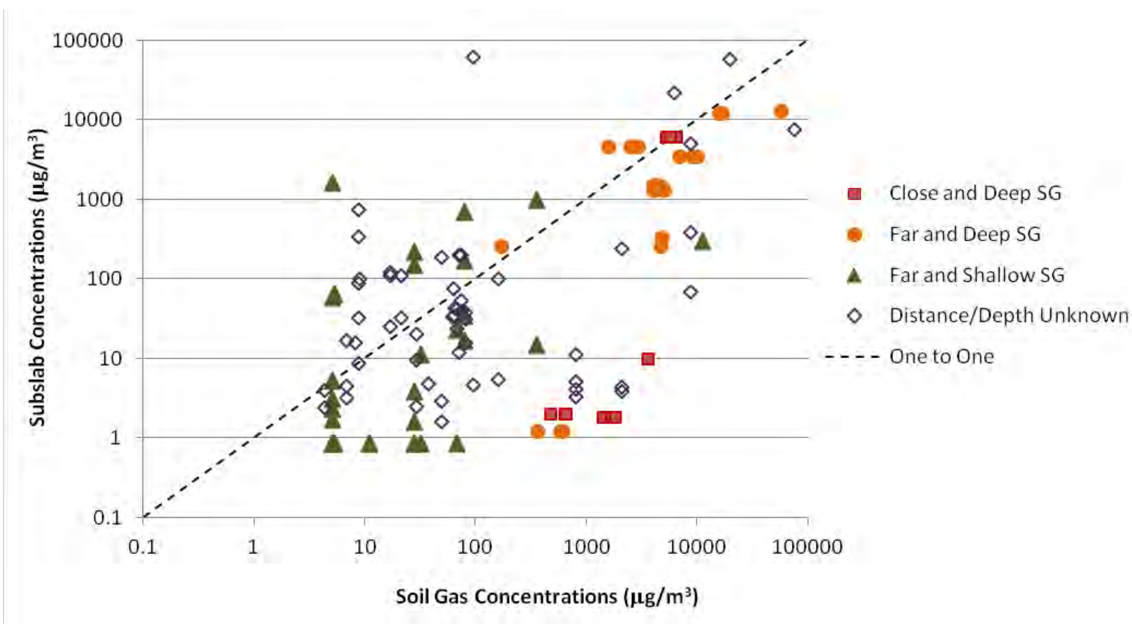

Figure B-5. Exterior soil gas versus sub-slab soil gas concentrations for buildings with both types of data in EPA's vapor intrusion database differentiated qualitatively by horizontal distance to building and depth to the exterior soil gas sample. SOURCE: Figure 6 in EPA (2012a).

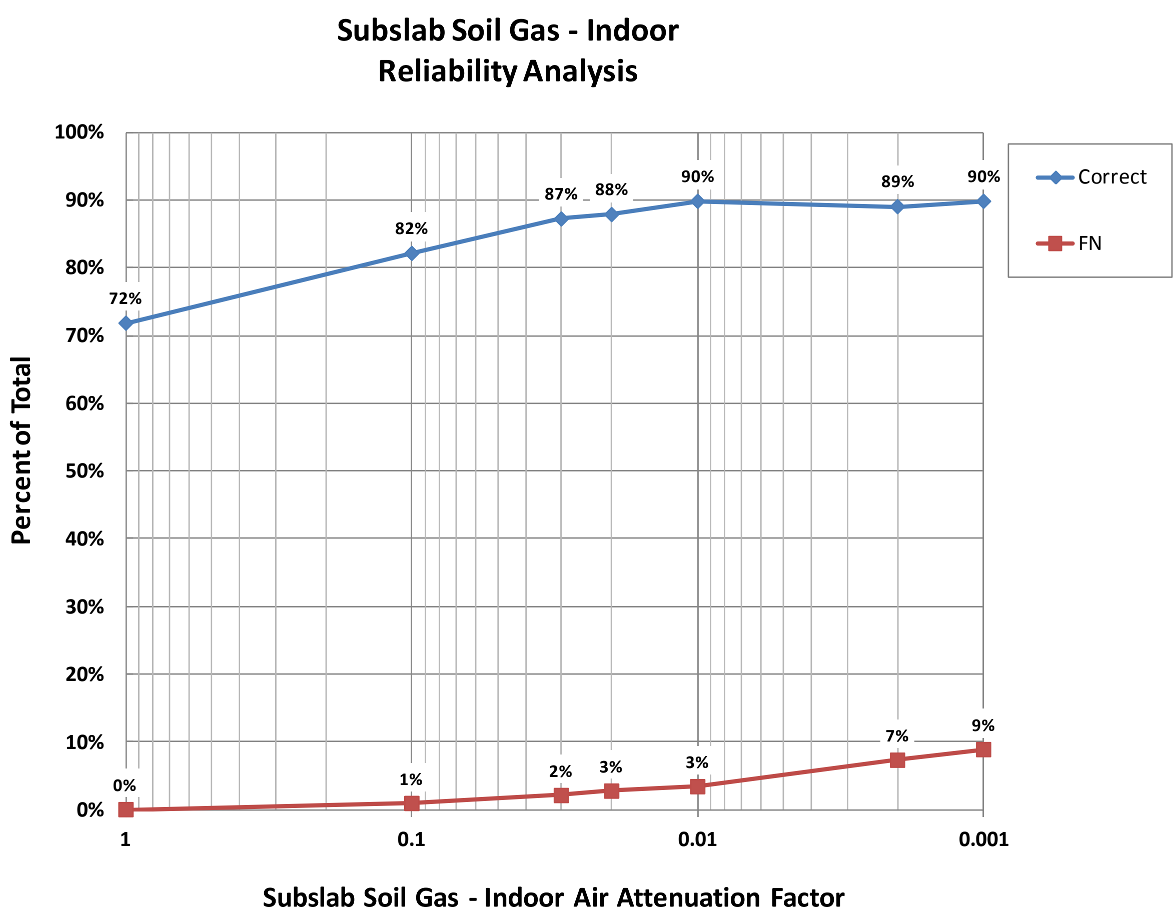

Figure B-6. Reliability Predictions for Alternative Choices of the Sub-slab Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset [tabulated values shown below]

Reliability Analysis: Subslab Soil Gas - Indoor Air

Classification	SS AF = 1	SS AF = 0.1	SS AF = 0.03	SS AF = 0.02	SS AF = 0.01	SS AF = 0.002	SS AF = 0.001
Correct	**551**	**630**	**669**	**674**	**689**	**683**	**689**
FN	**0**	**7**	**16**	**21**	**26**	**56**	**68**
Total	767	767	767	767	767	767	767

SS AF	**1**	**0.1**	**0.03**	**0.02**	**0.01**	**0.002**	**0.001**
Correct	**72%**	**82%**	**87%**	**88%**	**90%**	**89%**	**90%**
FN	0%	1%	2%	3%	3%	7%	9%

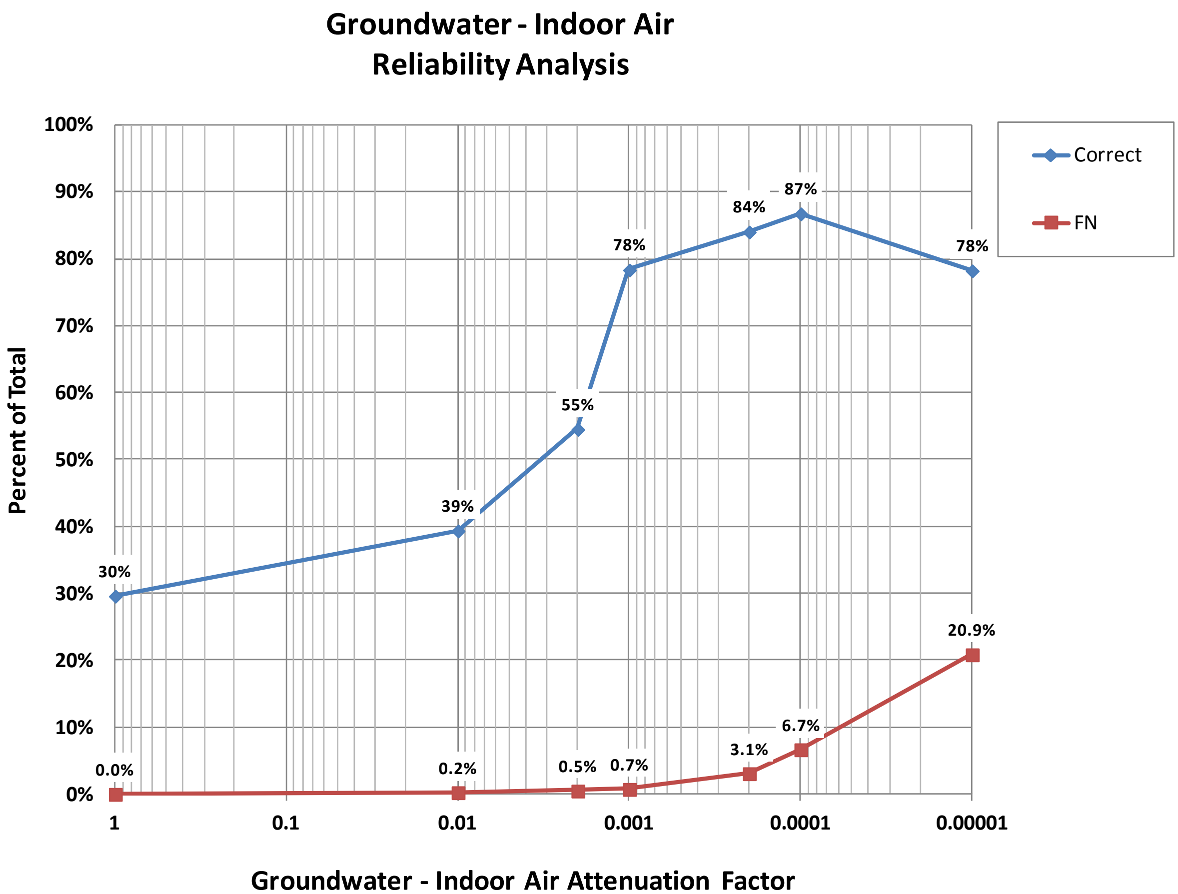

Figure B-7. Reliability Predictions for Alternative Choices of the Groundwater Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset
[tabulated values shown below]

Reliability Analysis: Groundwater -Indoor Air

Classification	GW AF = 1	GW AF = 0.01	GW AF = 0.002	GW AF = 0.001	GW AF = 0.0002	GW AF = 0.0001	GW AF = 0.00001
Correct	**240**	**319**	**442**	**635**	**681**	**703**	**634**
FN	**0**	**2**	**4**	**6**	**25**	**54**	**169**
Total	810	810	810	810	810	810	810

GW AF	**1**	**0.01**	**0.002**	**0.001**	**0.0002**	**0.0001**	**0.00001**
Correct	**30%**	**39%**	**55%**	**78%**	**84%**	**87%**	**78%**
FN	**0.0%**	**0.2%**	**0.5%**	**0.7%**	**3.1%**	**6.7%**	**20.9%**

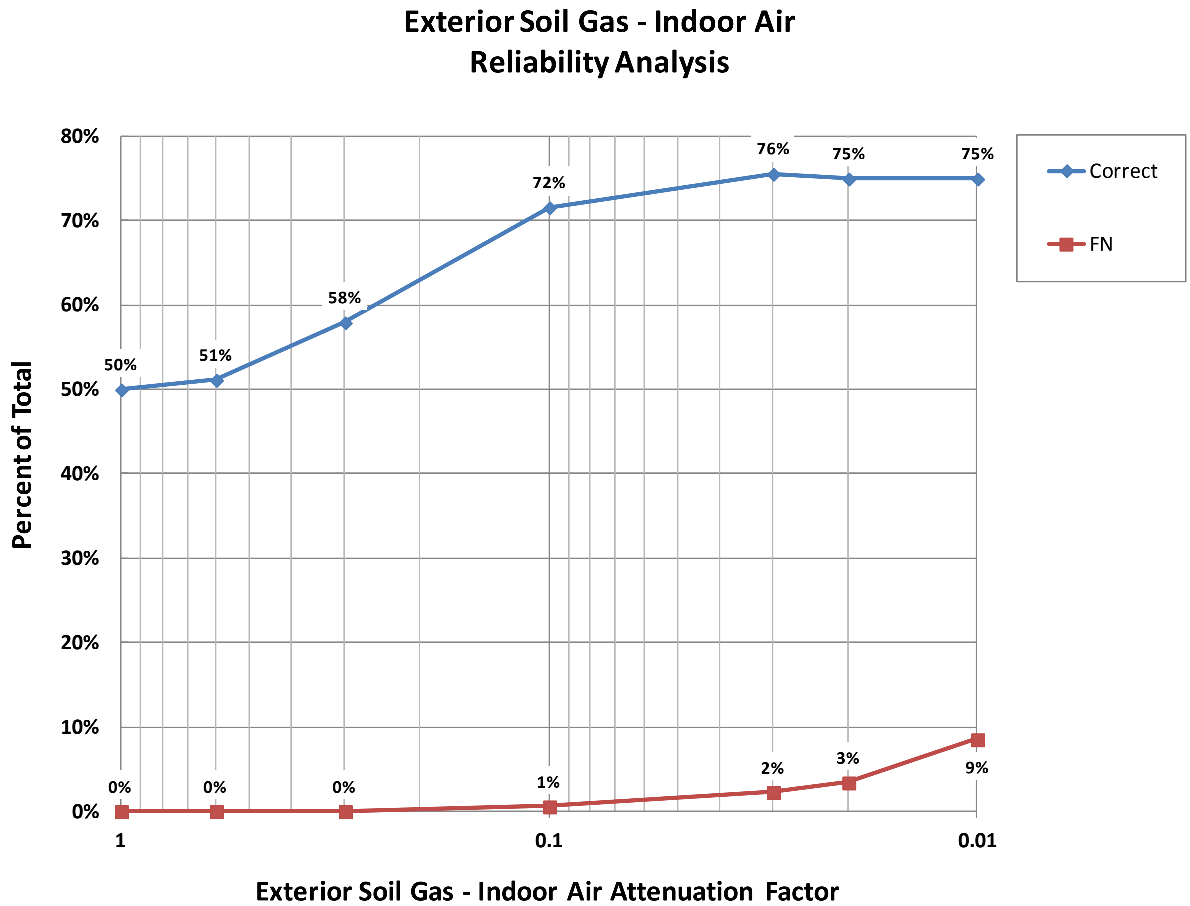

Figure B-8. Reliability Predictions for Alternative Choices of the Exterior Soil Gas Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset
[tabulated values shown below]

Reliability Analysis: Exterior Soil Gas - Indoor Air

Classification	SG AF = 1	SG AF = 0.6	SG AF = 0.3	SG AF = 0.1	SG AF = 0.03	SG AF = 0.02	SG AF = 0.01
Correct	88	90	102	126	133	132	132
FN	0	0	0	1	4	6	15
Total	176	176	176	176	176	176	176

SG AF	1	0.6	0.3	0.1	0.03	0.02	0.01
Correct	50%	51%	58%	72%	76%	75%	75%
FN	0%	0%	0%	1%	2%	3%	9%

APPENDIX C
DATA QUALITY ASSURANCE CONSIDERATIONS

C.1.0 INTRODUCTION

Site-specific investigations of the vapor intrusion pathway will generally require the collection and evaluation of environmental data and possibly the use of modeling. As noted in Exhibit C-1, EPA generally recommends the use of a quality assurance project plan (QAPP) for the collection of primary (and existing or secondary) data. A QAPP is a tool for project managers and planners to document the type and quality of data needed to make environmental decisions and to describe the methods for collecting and assessing the quality and integrity of those data. A QAPP is a plan or roadmap intended to help a project team document how they plan, implement, and evaluate a project. It applies the systematic planning process and the graded approach for collecting environmental data for a specific intended use. EPA standards governing the collection of data are outlined in Exhibit C-1.

Exhibit C-1. EPA Data Standards

CIO 2105 (formerly EPA Order 5360; *Policy and Program Requirements for the Agency-wide Quality System*, May 2000) requires that (1) the organization collecting or using the data has an established Quality System and (2) the project has an approved QAPP.

For clarity, CIO 2105 will be replaced by the following two standards:

- CIO 2106-S-01 is the *Quality Standard for Environmental Data Collection, Production, and Use by EPA Organizations*, also called "Internal Standard" (EPA 2013a); and
- CIO 2106-S-02 is the *Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations*, also called "External Standard" (EPA 2013b).

These standards conform to *EPA Quality Policy*, CIO 2106.0, "Quality Policy" (EPA 2008a), *Procedure for Quality Policy,* CIO 2106-P-01.0, "Quality Procedure" (EPA 2008b), and the American National Standards Institute (ANSI) consensus standard, *Quality Systems for Environmental Data and Technology Programs – Requirements with Guidance for Use* (ANSI/ASQ 2004).

Two guidance documents accompany these standards:

- *EPA Guidance on Quality Management Plans* (EPA 2012b, CIO 2106-G02-QMP), documents the quality system of the organization conducting environmental data collection or using the data for EPA.

- *EPA Guidance on Quality Assurance Project Plans* (EPA 2012a, CIO 2106-G-05) focuses on projects requiring the collection of new data, projects using existing data, and projects involving modeling.

EPA also encourages the use of the *Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP)* (EPA/DoD 2005) as a collaborative approach to satisfy EPA's requirement for a QAPP, especially for Federal Facilities. OSWER Directive 9272.0-17, *Implementation of the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) at Federal Facility Hazardous Waste Sites* (EPA 2005a) and OSWER Directive 9272.0-20 (EPA 2005b) state that QAPPs prepared and approved under the UFP conform to EPA's quality standards and are consistent with EPA Standards CIO 2106-S-0 and CIO 2106-S-02, EPA's Quality Policy (EPA 2008a), and ANSI/ASQ 2004.

C.2.0 RECOMMENDATIONS

This appendix provides two recommendations concerning the key components of QAPP development. These recommendations are not exhaustive, but are included as a starting point as considerations before studying or applying EPA or UFP QAPP guidance.

Recommendation 1: Using the conceptual site model (CSM), develop the project plan and QAPP through a process that involves all key players and share these materials with interested parties in draft form so that potential study weaknesses can be addressed early. The CSM is developed to portray the current understanding of site conditions, the nature and extent of contamination, routes of contaminant transport, potential contaminant pathways, and potentially exposed human populations. Developing the CSM is the first step in EPA's DQO process.

Recommendation 2: Use systematic planning in developing project documents, including the QAPP. Systematic planning is a science-based, common-sense approach designed to ensure that the level of documentation and rigor of effort in planning is commensurate with the intended use of the information and available resources. DQOs are a key component of systematic planning and play a central role in the systematic planning process. DQOs generally are addressed within the QAPP and typically are a critical element in the planning for environmental investigations. *Guidance on Systematic Planning Using the Data Quality Objectives Process (QA/G-4)* (EPA 2006) provides guidance addressing implementation of DQOs and application of systematic planning to generate performance and acceptance criteria for collecting environmental data.

Table C-1 summarizes the steps in the DQO process, the purpose of each step, and provides some examples of how plans could be structured.

TABLE C 1. EXAMPLE OF STEPS IN THE DQO PROCESS

DQO Step	Purpose of the DQO Step	Example Application for Vapor Intrusion
1. State the Problem	Summarize the problem that will require new environmental data (the monitoring hypothesis, the investigation objective(s)) or modeling.	Indoor air in one or more buildings overlying a shallow plume of PCE-contaminated groundwater is (are) to be sampled to determine whether PCE is present. The original PCE release occurred at an industrial site approximately 1,000 feet away from the closest building.
2. Identify the Decision	Identify the decision that requires new data or analysis to address the problem.	The data will be used to support decisions about whether additional indoor air sampling or preemptive vapor intrusion mitigation will be pursued in one or more buildings.
3. Identify the Inputs to the Decision	Identify the information needed to support the decision and specify the inputs that will require new information.	Indoor air sampling data for one or more buildings, in conjunction with information about measured or interpolated concentrations in groundwater near or underneath the building(s).
4. Define the Boundaries of the Study	Specify the spatial and temporal aspects of the environmental media or endpoints that the data must represent to support the decision.	The boundaries of this initial study area extend a prescribed distance outside the lateral extent of the plume. Eventually, the boundaries of a vapor intrusion impact zone will be defined by the extent to which indoor air contamination can be associated with site-related contamination.
5. Develop a Decision Rule	Develop a logical "if…then" statement that defines the conditions that will inform the decision-maker to choose among alternative decisions.	Buildings with detectable concentrations of PCE in indoor air samples will be considered for additional indoor air sampling or preemptive vapor intrusion mitigation.
6. Specify Tolerable Limits on Decision Errors	Specify acceptable limits on decision errors, which are used to establish performance goals for limiting uncertainty in the analysis.	Analytical limits of detection should be less than risk-based screening levels for PCE to ensure that a building's indoor air concentration is not misidentified.
7. Optimize the Design for Obtaining Data	Identify the most resource-effective sampling and analysis design for generating the information needed to satisfy the DQOs.	Time-integrated samples will be collected in basements and in the first above-ground level of each building. The sampling and analysis plan and approach will be documented in a QAPP.

C.3.0 CITATIONS AND REFERENCES

ANSI/ASQ. 2004. *Quality Systems for Environmental Data and Technology Programs – Requirements with Guidance for Use. E4-2004.* http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI/ASQ+E4-2004

U.S. Environmental Protection Agency (EPA). 2000. *Policy and Program Requirements for the Agency-wide Quality System*. EPA Order CIO 2105. May. http://www.epa.gov/irmpoli8/policies/21050.pdf

U.S. Environmental Protection Agency (EPA). 2005a. *Implementation of the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) at Federal Facility Hazardous Waste Sites.* OSWER Directive 9272.0-17. June 7. http://www.epa.gov/fedfac/pdf/oswer_qapp_directive.pdf

U.S. Environmental Protection Agency (EPA). 2005b. *Applicability of the Uniform Federal Policy for Quality Assurance project Plans (EPA-505-04-900A)*. *OSWER Directive* 9272.0-20. December 5. http://www.epa.gov/fedfac/pdf/oswer_9272.0_20.pdf

U.S. Environmental Protection Agency (EPA). 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process (QA/G-4)*. EPA/240/B-06/001. February 2006. http://www.epa.gov/quality/qs-docs/g4-final.pdf

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U.S. Environmental Protection Agency (EPA). 2008b. *U.S. Environmental Protection Agency Procedure for Quality Policy*. CIO 2106-P-01.0. http://www.epa.gov/irmpoli8/policies/21060.pdf

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U.S. Environmental Protection Agency (EPA), 2012b. *EPA Draft Final Guidance on Quality Management Plans.* CIO 2106-G02-QMP. January 17. http://www.epa.gov/oeitribalcoordination/2106-G-05%20QAPP%20Final%20Draft%2001-17-12.pdf

U.S. Environmental Protection Agency (EPA). 2013a. *Quality Standard for Environmental Data Collection, Production, and Use by EPA Organizations.* CIO 2106-S-01.

U.S. Environmental Protection Agency (EPA). 2013b. *Draft Final Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations* (CIO 2106-S-02) “External Standard.” February 22. http://www.epa.gov/oeitribalcoordination/External%20Standard%20with%20Annexes.pdf

U.S. Environmental Protection Agency and U.S. Department of Defense (EPA/DoD). 2005. *Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP). Part 1: UFP-QAPP Manual.* EPA Publication EPA-505-B-04-900A. DoD Publication DTIC ADA 427785. March. http://www.epa.gov/fedfac/pdf/ufp_qapp_v1_0305.pdf

APPENDIX D
CALCULATING VAPOR SOURCE CONCENTRATION FROM GROUNDWATER SAMPLING DATA

Correcting the Henry's Law Constant for Groundwater Temperature

In the case of groundwater as the vapor source, the subsurface source concentration (C_{sv}) is estimated assuming that the vapor and aqueous phases are in local equilibrium according to Henry's law such that:

$$C_{sv} = H'_{TS} \times C_w \qquad \text{Equation D.1}$$

where:

C_{sv} = vapor concentration at the source of contamination (g/cm^3-v),

H'_{TS} = Henry's law constant at the system (groundwater) temperature (dimensionless), and

C_w = concentration of volatile chemical in groundwater (g/cm^3-w).

The Henry's law constants generally are reported for a temperature of 25 degrees Celsius (^oC). **Table D-1** provides these values for the chlorinated hydrocarbons (CHCs) in the vapor intrusion database. Average groundwater temperatures, however, are typically less than 25^oC. In such cases, use of the Henry's law constant at 25^oC may over-predict the volatility of the contaminant in water.

As described in EPA's *Soil Screening Guidance* (EPA 1996), the dimensionless form of the Henry's law constant at the average groundwater temperature (H'_{gw}) may be estimated using the Clapeyron equation:

$$H'_{gw} = \frac{\exp\left[-\frac{\Delta H_{v,gw}}{R_c} \times \left(\frac{1}{T_{gw}} - \frac{1}{T_R}\right)\right] H_R}{R \times T_{gw}} \qquad \text{Equation D.2}$$

where:

$\Delta H_{v,gw}$ = enthalpy of vaporization of the specific chemical at the groundwater temperature (cal/mol),

T_{gw} = groundwater temperature ($^\circ K = {}^oC + 273.15$),

T_R = reference temperature for the Henry's law constant (298.15^oK),

R_C = gas constant (= 1.9872 cal/mol-^oK),

H_R = Henry's law constant for the specific substance at the reference temperature ($atm\text{-}m^3/mol$), and

R = gas constant (= 8.205 E-05 $atm\text{-}m^3/mol\text{-}^oK$).

The enthalpy of vaporization at the groundwater temperature can be approximated from the enthalpy of vaporization at the normal boiling point, as follows:

$$\Delta H_{v,gw} = \Delta H_{v,b}\left[\frac{(1-T_{gw}/T_C)}{(1-T_B/T_C)}\right]^{\eta} \quad \text{Equation D.3}$$

where:

$\Delta H_{v,gw}$ = enthalpy of vaporization at the groundwater temperature (cal/mol),

$\Delta H_{v,b}$ = enthalpy of vaporization at the normal boiling point (cal/mol),

T_C = critical temperature for specific chemical (^oK),

T_B = normal boiling point for specific chemical (^oK),

η = exponent (unitless), and

all other symbols are as defined previously. **Table D-1** provides the chemical-specific property values used for temperature corrections to the Henry's law constant. **Table D-2** provides the value of η as a function of the ratio T_B/T_C. If site-specific data are not readily available for the groundwater temperature, then Figure 1 of the EPA fact sheet, *Correcting the Henry's Law Constant for Soil Temperature* (EPA 2001) can be used to generate an estimate.

Citations

EPA (U.S. Environmental Protection Agency). 1996. *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95/128. Office of Solid Waste and Emergency Response. Washington, DC. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/introtbd.htm.

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Mallard, W.G. and P.J. Linstrom (Eds.). 1998. *NIST Chemistry WebBook, NIST Standard Reference Database Number 69.* November. Gaithersburg, MD. National Institute of Standards and Technology. Available at http://webbook.nist.gov/chemistry/.

Table D-1. Chemical-Specific Parameters for Adjusting Henry's Law Coefficients for Groundwater Temperature

Chemical Abstracts Service Registry Number (CASRN)	Alphabetized List of Compounds	Henry's Law Constant @25°C		Henry's Law Constant @25°C[g]	Normal Boiling Point		Critical Temperature		Enthalpy of vaporization at the normal boiling point	
		H_R		H'_R	T_b		T_c		$\Delta H_{v,b}$	
		(atm-m^3/mol)	source	(unitless)	(^oK)	source	(^oK)	source	(cal/mol)	source
56-23-5	Carbon tetrachloride	2.76E-02	a	1.13E+00	3.50E+02	b	5.57E+02	h	7.13E+03	h
75-00-3	Chloroethane (ethyl chloride)	1.11E-02	a	4.54E-01	2.85E+02	b	4.60E+02	f	5.88E+03	f
67-66-3	Chloroform	3.67E-03	a	1.50E-01	3.34E+02	b	5.36E+02	h	6.99E+03	h
75-34-3	Dichloroethane,1,1-	5.62E-03	a	2.30E-01	3.30E+02	b	5.23E+02	h	6.90E+03	h
75-35-4	Dichloroethene, 1,1-	2.61E-02	a	1.07E+00	3.05E+02	b	5.76E+02	h	6.25E+03	h
156-59-2	Dichloroethene,cis-1,2-	4.08E-03	a	1.67E-01	3.28E+02	b	5.44E+02	h	7.19E+03	h
156-60-5	Dichloroethene,trans-1,2-	4.08E-03	a	1.67E-01	3.28E+02	b	5.17E+02	h	6.72E+03	h
75-09-2	Methylene chloride	3.25E-03	a	1.33E-01	3.13E+02	b	5.10E+02	h	6.71E+03	h
127-18-4	Tetrachloroethene	1.77E-02	a	7.23E-01	3.94E+02	b	6.20E+02	h	8.29E+03	h
76-13-1	Trichloro-1,2,2-trifluoroethane,1,1,2-	5.26E-01	a	2.15E+01	3.21E+02	b	4.87E+02	f	6.46E+03	f
71-55-6	Trichloroethane, 1,1,1-	1.72E-02	a	7.03E-01	3.47E+02	b	5.45E+02	h	7.14E+03	h
79-01-6	Trichloroethene	9.85E-03	a	4.03E-01	3.60E+02	b	5.44E+02	h	7.51E+03	h
75-01-4	Vinyl chloride (chloroethene)	2.78E-02	a	1.14E+00	2.60E+02	b	4.32E+02	h	5.25E+03	h

Sources and Footnotes:

a Based on values reported in the U.S. EPA Regional Screening Tables. November 2011. Available online at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/xls/params_sl_table_run_NOV2011.xls

b Experimental values. EPA 2009. *Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.00*. U.S EPA, Washington, DC, USA. Available online at: http://www.epa.gov/opptintr/exposure/pubs/episuite.htm

f *CRC Handbook of Chemistry and Physics, 76th Edition*

h EPA (2001). FACT SHEET *Correcting the Henry's Law Constant for Soil Temperature*. Attachment.

g National Institute of Standards and Technology (NIST). *Chemistry WebBook*. Available online at http://webbook.nist.gov/chemistry/

Table D-2. Values of Exponent η as a Function of T_B/T_C

Chemical-specific ratio T_B/T_C	H
< 0.57	0.30
0.57 - 0.71	0.74 (T_B/T_C) - 0.116
> 0.71	0.41