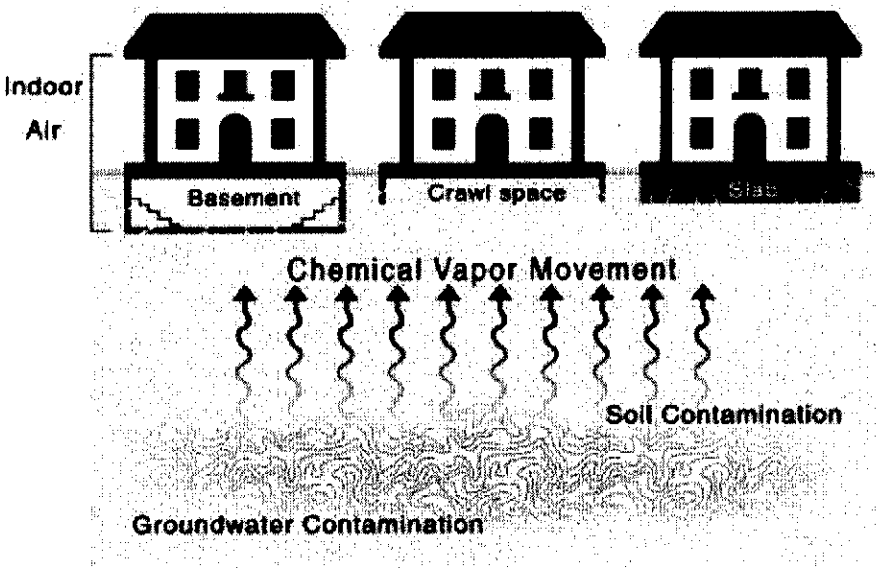
Vapor Intrusion Guidance



(EPA Region 3)

July 2006

NEW HAMPSHIRE
DEPARTMENT OF
Environmental Services

Vapor Intrusion Guidance

Prepared by
Site Remediation Programs
Waste Management Division
New Hampshire Department of Environmental Services
29 Hazen Drive
Concord, NH 03302-0095
www.des.nh.gov
(603) 271-3503

Michael P. Nolin, Commissioner
Michael J. Walls, Assistant Commissioner
Anthony P. Giunta, Director, Waste Management Division

July 2006

NEW HAMPSHIRE DEPARTMENT OF Environmental Services

Table of Contents

SECTION TITLE **PAGE**

1.0 PURPOSE 1

2.0 HOW VAPOR INTRUSION OCCURS
- 2.1 General Concepts 1
- 2.2 Factors that Affect Vapor Intrusion 2

3.0 EVALUATING THE VAPOR INTRUSION PATHWAY
- 3.1 General Considerations 3
- 3.2 Method 1 Approach 4
- 3.3 Site Specific Pathway Assessment 6

4.0 METHOD 1 VAPOR INTRUSION SCREENING LEVELS
- 4.1 Groundwater Screening Levels 6
- 4.2 Soil Gas Screening Levels 7
- 4.3 Indoor Air Screening Levels 7

5.0 SOIL GAS SAMPLING PROCEDURES
- 5.1 Overview 8
- 5.2 Designing a Soil Gas Sampling Plan 8
- 5.3 Field Screening 9
- 5.4 Soil Gas Probes 9
- 5.5 Sample Collection and Analysis 10
- 5.6 Soil Gas Data Evaluation 13

6.0 INDOOR AIR SAMPLING
- 6.1 General Approach 13
- 6.2 Site Inspection, Product Inventory and Field Screening 14
- 6.3 Sample Collection and Analysis 14
- 6.4 Background 15
- 6.5 Sampling under Conservative Conditions 16
- 6.6 OSHA Considerations 17

7.0 EVALUATION OF RESULTS 17

8.0 ADDITIONAL INVESTIGATIVE TOOLS
- 8.1 Determination of a Site-specific Soil Gas Attenuation Factor 19
- 8.2 Indoor/sub-slab Differential Pressure Measurements 19
- 8.3 Passive Soil Gas 20
- 8.4 Flux Chambers 20
- 8.5 Modeling 20

9.0 VAPOR INTRUSION ABATEMENT STRATEGIES 21

10.0 REFERENCES 23

TABLES

Table 1 Vapor Intrusion Screening Levels 25

FIGURES

Figure 1 Simplified Vapor Intrusion Conceptual Model 2
Figure 2 Evaluating the Vapor Intrusion Pathway..... 26
Figure 3 Soil Gas Sampling Probes 10
Figure 4 Permanent Soil Gas Probe 11
Figure 5 Sub-slab Soil Gas Probe 11
Figure 6 Sub-slab Soil Depressurization System..... 22

APPENDICES

APPENDIX A Vapor Intrusion Conceptual Site Model Checklist 27
APPENDIX B Soil Gas Probe Field Data Report 29
APPENDIX C Indoor Air Sampling Form..... 30
APPENDIX D Indoor Air Sampling Protocol.... 33
APPENDIX E Derivation of the Indoor Air Screening Levels.. 36

1.0 PURPOSE

This document provides guidance for the evaluation and mitigation of vapor intrusion resulting from volatile organic compounds (VOC) at contaminated sites in New Hampshire. Where appropriate this document may be used in conjunction with applicable DES rules for corrective action at contaminated sites and the DES Risk Characterization and Management Policy (RCMP).

An often overlooked exposure pathway involves VOC vapor movement from contaminated soil and/or groundwater and residual or mobile non-aqueous phase liquid (NAPL) through the subsurface into nearby buildings where occupants can be exposed. Commonly referred to as the vapor intrusion pathway, this pathway can be complicated to evaluate in terms of assessing risk to human health as there are many factors that influence the migration of vapors in the subsurface. This document provides the following:

- A review of basic vapor intrusion concepts.
- A discussion of a multiple line of evidence approach for assessing the pathway.
- A review of DES screening levels for groundwater, soil gas and indoor air.
- A review of soil gas sampling techniques.
- A review of indoor air sampling techniques.
- A review of vapor intrusion abatement strategies.
- An approach for conducting a site-specific risk assessment.
- A list of references.

2.0 HOW VAPOR INTRUSION OCCURS

2.1 General Concepts

Vapor intrusion occurs when VOCs migrate from contaminated soil and/or groundwater or residual or mobile NAPL through the subsurface to the indoor air of a building. This pathway can also be a potential issue for future buildings located above or near VOC contamination. Vapor intrusion sites can involve petroleum contaminants from leaking underground storage tanks and spills as well as chlorinated solvents and pesticides from commercial, industrial and landfill sites. This policy does not specifically address issues associated with landfill gases such as methane; however some of the same assessment and mitigation techniques may be appropriate for those sites. Vapor intrusion related to non-VOCs such as mercury, are not specifically addressed in this policy and would continue to be handled on a case by case basis.

In general, VOC vapor intrusion sites are grouped into two categories: petroleum hydrocarbons and chlorinated solvents. Projects involving vapor intrusion of chlorinated solvents have the potential to be more complicated to evaluate than petroleum contaminants because of their greater mobility, the lack of good warning properties such as low odor thresholds, and limited potential to undergo biodegradation.

Figure 1 below presents a simplified vapor conceptual site model of a scenario where the source of contamination is located some distance from an occupied structure. At the top boundary of the subsurface contamination, molecular diffusion results in the movement of chemicals from areas of higher concentration to lower concentration. The contaminant vapors diffuse up towards

the structure until reaching the building's zone of influence. Once the VOCs enter the building's zone of influence differential pressure gradients control the vapor movement in the proximity of the structure. Since the air pressure inside a structure is commonly less than the pressure in the subsurface, the vapor migrates by bulk air flow (advection) through cracks or openings (e.g., floor drains) in the foundation or basement slab into the structure in response to "inward" pressure gradients. Advection can be induced by atmospheric pressure fluctuations and stack effects due to building heating and mechanical ventilation systems. Negative pressure gradients (i.e., lower air pressure inside a structure versus soil vapor pressure) can be greatest when heating systems are in operation. Advection is likely the dominant process near a structure.

Diffusion, which is the concentration gradient-driven migration, is commonly accepted to be the dominant process away from the building foundation or where the water table is shallow and the soil adjacent to the foundation is mostly water saturated. Where preferential pathways exist, the vapor conceptual site model shown below would be different.

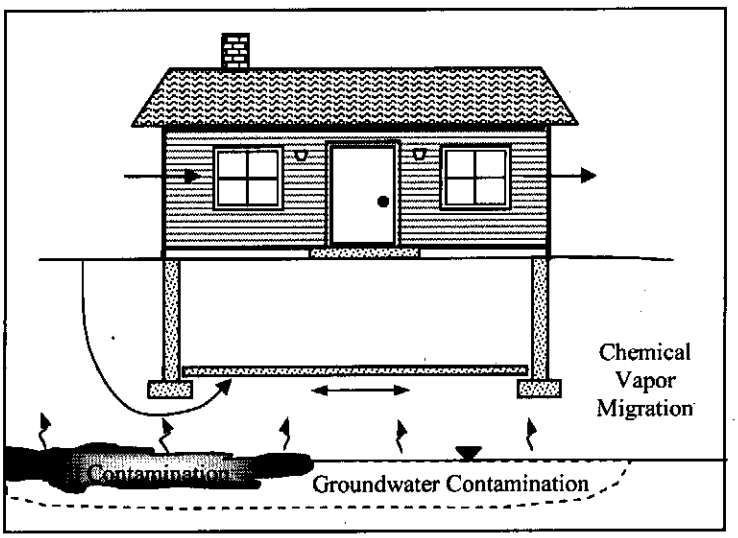


Figure 1. Simplified vapor intrusion conceptual model

2.2 Factors That Affect Vapor Intrusion

Many factors can influence contaminant vapor movement in the subsurface and potentially cause a human health risk to a building occupant. Conditions that influence vapor intrusion can include:

- Construction style – Vapor intrusion occurs in structures with or without basements. Investigation of sites in other states has found that even slab-on-grade construction can be affected by vapor intrusion. The condition and construction of the foundation and presence/absence of an adequate vapor barrier can be important factors to consider. Positive pressure HVAC systems can prevent vapor intrusion.

- Structure age – Older structures are less likely to have adequate vapor barriers incorporated into the foundation construction and the foundation itself is more likely to have developed cracks.

- Dirt floors and stone foundations – Earthen floors or fieldstone foundations are more porous and provide increased opportunity for vapor intrusion.

- Drain tile/sumps – If the building has a foundation drain tile connected to a sump even low level VOC concentrations in the water can contribute to indoor air problems.

- Wet basements – If the building has water infiltrating into the basement dissolved VOCs can volatilize into the indoor air. Wet basements can indicate a shallow water table or be related to drainage problems.

- Utility lines – Gaps or cracks around piping or other utility lines that enter a building can be an important preferential migration pathway for vapors. Permeable soil in a utility trench can also provide a conduit for contaminants to migrate significant distances from the source area.

- Proximity of contamination to buildings – Vapor intrusion should be an obvious concern when buildings are very close to the source of VOC contamination.

- Shallow groundwater – The potential for vapor intrusion typically decreases with increasing depth to groundwater for some chemicals particularly those that are known to biodegrade such as petroleum hydrocarbons.

- Soil type and moisture content– Soil type influences the transport of contaminants in soil vapor and groundwater. Coarse-grained soil types can promote contaminant migration over long distances, but also provides easier venting to the atmosphere. Fine grained or tight soils with higher moisture content will tend to inhibit vapor contaminant transport. The soil stratigraphy is also important in developing a conceptual site model of soil gas migration.

- Fractured bedrock – Shallow fractured bedrock connected to a subsurface source of VOCs can increase vapor intrusion potential by encouraging faster soil gas migration. This becomes a greater concern when the bedrock is at or near the base of a building foundation.

- Degradation – Petroleum hydrocarbons can biodegrade relatively quickly in unsaturated soils. In contrast chlorinated solvents will likely undergo limited biodegradation and, therefore, may have the ability to cause a vapor intrusion impact a long distance away from the VOC source.

3.0 EVALUATING THE VAPOR INTRUSION PATHWAY

3.1 General Considerations

DES recommends that the vapor intrusion pathway be evaluated at sites were there is a source of VOC contamination near an occupied building(s). VOC contaminated groundwater is considered to be a potential source of vapors of contaminants to indoor air. The GW-2 groundwater screening values are intended to provide guidelines on when it may be appropriate to examine the indoor air exposure pathway. The GW-2 groundwater screening values are intended to be used where VOCs (non-petroleum) are detected in groundwater above the GW-2 levels within 100 feet (vertically or horizontally) of an occupied building. At petroleum hydrocarbon sites, the GW-2

screening values are intended to be applied where petroleum VOCs are detected in groundwater above the GW-2 levels within 30 feet (vertically or horizontally) of an occupied building.

In order to evaluate the potential for vapor intrusion into buildings, DES recognizes two methods for evaluating the vapor intrusion pathway. The first is a Method 1 approach using screening levels where multiple lines of evidence are obtained to determine if the vapor intrusion pathway is complete, and if so, whether there is a significant risk to building occupants. The Method 1 approach includes screening levels for groundwater, soil gas, and indoor air. The second approach is a site-specific vapor intrusion pathway assessment. The two methods for evaluating the vapor intrusion pathway are discussed in more detail in Sections 3.2 and 3.3 below.

Vapors emanating from contaminated groundwater at some depth below a building are not the only VOC sources that may result in an indoor air exposure. The scenarios listed below can also result in an indoor air exposure with or with out exceeding a GW-2 screening value. It may be appropriate to evaluate the vapor intrusion pathway for the following scenarios:

- Where a vadose zone VOC source from contaminated soil or a vapor release are located near a building;
- Where a significant preferential pathway exists that connects a VOC source with a nearby building;
- Where NAPL is located near a building;
- Where VOC odors attributable to a release under investigation are detectable inside a structure indicating that the indoor air exposure pathway is likely complete; or
- Where contaminated groundwater has or continues to enter a structure and the VOCs are volatilizing into the indoor air space creating an exposure.

Where the indoor air exposure pathway is complete, indoor air sampling to assess the potential risk to human health is recommended. Where the potential risk is determined to be significant, mitigation efforts should be evaluated and implemented as appropriate including any follow up monitoring. Section 9.0 describes strategies that may be appropriate for mitigating vapor intrusion.

3.2 Method 1 Approach

The Method 1 approach is typically a multiple step process as outlined below. Multiple lines of evidence are used to determine whether the vapor intrusion pathway is complete, and if so, whether there is a significant risk to building occupants. Site data is collected and compared to the appropriate Method 1 screening levels. The screening levels are listed in Table 1 and are further explained in Section 4.0 and are identified as follows:

- Groundwater to indoor air screening levels.
- Soil gas screening levels (residential and commercial).
- Indoor air screening levels (residential and commercial).

The vapor intrusion Method 1 screening value lookup numbers in Table 1 may not be appropriate for all sites, and it may not be necessary to sample all three media (groundwater, soil gas, and indoor air) at all sites to determine if vapor intrusion is a pathway of concern. Each step of the screening process provides additional lines of evidence that the pathway is likely complete, indicating that further

evaluation of the pathway may be necessary or the pathway is incomplete. Figure 2 provides a flow chart on evaluating the vapor intrusion pathway. DES does not have bulk soil sample screening levels for evaluating the vapor intrusion pathway. As a result, where bulk soil sample data indicates a vadose zone source of VOCs, soil gas data and/or indoor air data should be collected to assess the vapor intrusion pathway. When sampling groundwater, soil gas, or indoor air for comparison with the vapor intrusion screening levels, multiple sampling events that cover the expected range of conditions that may influence concentrations, should be conducted (i.e., seasonal, atmospheric, hydrogeologic, etc.).

Typically the first step in the Method 1 approach is comparison of groundwater data collected from the study area to the GW-2 values summarized in Table 1. In general, when evaluating a dissolved phase plume where other potential vapor intrusion factors are not a concern (i.e. NAPL, vadose zone VOC source, contaminated groundwater seeping into a building), if all compounds of concern (COC) in groundwater are less than the respective GW-2 values, the pathway is determined to be incomplete. If a COC in groundwater exceeds the GW-2 value near a structure, further assessment of the pathway should be conducted.

If an exceedance of a GW-2 value has been identified in the study area, the next step in the Method 1 approach would be to conduct an exterior soil gas sampling program to evaluate the soil gas vapor plume. When conducting soil gas sampling to assess the vapor intrusion pathway, DES recommends using the vapor intrusion conceptual site model check list included in Appendix A. Soil gas sampling is further detailed in Section 5.0. Soil gas data collected in the study area would then be compared to the soil gas screening levels in Table 1. If the levels in soil gas are less than the soil gas screening levels, it may be possible to rule out vapor intrusion as a potential pathway. See Section 7.0 for a discussion on evaluating results. If a COC exceeds a soil gas screening value, this provides additional evidence that there is a potential for vapor intrusion to nearby buildings and that further assessment should be conducted.

If an exceedance of a soil gas screening level has been identified during the exterior soil gas sampling program, further assessment will typically involve collection of indoor air samples from structures suspected of being impacted by vapor intrusion.

Indoor air concentrations should be compared to the indoor air screening levels in Table 1. If COC levels in indoor air are less than the indoor air screening levels further evaluation of the vapor intrusion pathway may not be necessary. If an exceedance of an indoor air screening level has been identified, and the pathway is determined to be complete, abatement measures, continued monitoring, or further assessment and/or evaluations may be necessary. Indoor air sampling and related indoor air background issues are discussed in Section 6.0. See Section 7.0 for a discussion on evaluating results.

If the pathway is determined to be complete, or likely complete, at any stage of the investigation a site specific health risk assessment can be completed in lieu of using the screening levels in Table 1. The frame work for conducting a site specific risk assessment for the vapor intrusion pathway is presented in Appendix E.

3.3 Site Specific Vapor Intrusion Pathway Assessment

A site specific vapor intrusion pathway assessment addresses a broad range of site conditions and can involve increasingly more sophisticated site-specific data collection, analysis, and data evaluation than the Method 1 approach.

The following vapor intrusion assessment tools may be useful when conducting a site specific vapor intrusion pathway assessment:

- Completing site specific cumulative risk calculations based on site specific exposure factors.
- Obtaining lateral and vertical soil gas profiles to demonstrate attenuation and/or biodegradation.
- Use of additional investigative tools as described in Section 8 including:
  - Determination of a site-specific soil gas attenuation factor using a conservative tracer
  - Indoor/sub-slab differential pressure measurements
  - Passive soil gas sampling
  - Flux chamber sampling
  - Modeling

The site specific vapor intrusion pathway assessment approach and results should be fully documented in a report that includes a conceptual site model of subsurface vapor transport mechanisms and site specific measurements and analysis. DES recommends that a work plan be submitted to the department for comment prior to completing a site specific vapor intrusion pathway assessment.

4.0 METHOD 1 VAPOR INTRUSION SCREENING LEVELS

DES has developed threshold screening levels for groundwater, soil gas, and indoor air for use in the Method 1 approach for evaluating the vapor intrusion pathway. Where any of the screening levels are exceeded at a site the vapor intrusion pathway should be evaluated further except where the indoor air levels are attributable to background. The following screening levels are based on a conservative inhalation risk exposure scenario.

4.1 Groundwater Screening Levels

As noted above DES recommends that the vapor intrusion pathway be evaluated at sites in New Hampshire where VOCs are detected in groundwater above the GW-2 levels within 100 feet (vertically or horizontally) of an occupied building. For petroleum hydrocarbon sites, the GW-2 levels would apply within 30 feet (vertically or horizontally) of an occupied building.

Where groundwater data exists for a site, the contaminant concentrations should be compared to the GW-2 values in Table 1. The GW-2 screening levels are intended to provide guidance on when it may be appropriate to examine the vapor intrusion pathway from a dissolved phase plume. The GW-2 screening levels will often provide the first step of the Method 1 vapor intrusion pathway assessment as groundwater data is often collected during the initial stages of any site investigation.

When installing groundwater monitoring wells for assessing the vapor intrusion pathway, wells should intersect the water table throughout the year, (i.e., a water table well) and have a water column

thickness of 10 feet or less. Where a clean water lens or a perched water table exists of sufficient thickness, vertical profiling of VOC levels in groundwater may be warranted.

At sites that may have contamination due to a vadose zone source including contaminated soil or vapor leaks, groundwater data may not be an appropriate tool for assessing the vapor intrusion pathway for these sources. Soil gas data would be the more appropriate investigative tool for assessing the risk from vadose zone sources.

4.2 Soil Gas Screening Levels

DES has developed two soil gas screening levels, residential and commercial, which are provided in Table 1. The soil gas screening levels in Table 1 may be used where deep exterior soil gas samples are collected adjacent to the structure(s) under investigation and at a depth below the anticipated depth of the foundation, or where sub-slab soil gas samples are collected immediately beneath the building. For residential structures with basements, DES recommends a depth of 10 feet below grade. Soil gas samples collected more than 10 feet horizontally away from a building may not be appropriate for assessing the vapor intrusion pathway. Due to potential variability in soil gas concentrations, multiple soil vapor probes and multiple sampling events that cover the expected range of conditions that may influence concentrations (depth, seasonal, atmospheric, hydrogeologic, etc.) may be necessary to determine if additional investigation of the vapor intrusion pathway may be necessary at a site. Soil gas sampling procedures are outlined in Section 5.0.

Two soil gas screening values have been developed based on different exposure scenarios that account for a residential exposure and for a commercial exposure. The general equation used to calculate the soil gas screening levels is noted below:

$$SG = C_{AIR} / \alpha_{SG}$$

SG = The soil gas screening level in units of $\mu g/m^3$.
C_{AIR} = Indoor air screening levels for the appropriate exposure scenario, residential or commercial in units of $\mu g/m^3$.
α_{SG} = Soil gas to indoor air attenuation factor of 0.02, dimensionless.

The soil gas screening values in Table 1 are not intended for use in assessing crawl space vapor samples. Where crawl space vapor samples are collected, the results should be compared with the indoor air screening values listing in Table 1.

4.3 Indoor Air Screening Levels

DES has developed two sets of indoor air screening levels for the evaluation of the vapor intrusion pathway. Residential and commercial indoor air screening levels are listed in Table 1. When vapor intrusion is of potential concern, indoor air concentrations may be evaluated using the indoor air screening levels to determine if further evaluation, monitoring or mitigation of the pathway is appropriate. Site-specific background sources should always be considered when interpreting indoor air data. Background contaminant levels, both indoors and from outdoor ambient air, may exceed the Table 1 indoor air screening levels for some compounds. Background determinations should be made on a site-specific basis as part of an overall multiple line of evidence data evaluation.

The indoor air screening levels were derived taking into consideration risk-based criteria, method reporting limits and indoor air background values (residential only). For more information on the risk based criteria and exposure assumptions used to calculate the residential and commercial indoor air screening levels see Appendix E.

For chemicals that have both a carcinogenic and non-carcinogenic value, separate risk-based levels were calculated with the lower (more protective) concentration selected based on the following:

- A concentration equal to 20 percent of a reference concentration (RfC) published by the USEPA or an analogous allowable concentration.
- An indoor air concentration associated with an excess lifetime cancer risk of one-in-one million.

The lower, more protective risk based value was then compared to a background value, if available, and the low level reporting limit for EPA Method TO-15, and the higher number was selected to represent the indoor air screening value listed in Table 1.

5.0 SOIL GAS SAMPLING PROCEDURES

5.1 Overview

The following section provides some basic guidelines for conducting soil gas sampling for assessing the vapor intrusion pathway. Soil gas sampling can be used for a number of purposes including initial site characterization, delineation of a groundwater plume, identification of source areas, evaluation of the vapor intrusion pathway, remediation and post-remediation monitoring. The guidelines outlined below are specific to the evaluation of the vapor intrusion pathway, but may be modified for other corrective action purposes. When soil gas sampling is to be used for assessing the vapor intrusion pathway, DES recommends that work plans be submitted to the department for comment prior to the initiation of fieldwork.

5.2 Designing a Soil Gas Sampling Plan

The development of a soil gas sampling plan, should be site specific, and establish the vapor migration conceptual site model and provide an assessment of the vapor intrusion pathway. DES recommends using the vapor intrusion conceptual site model check list included in Appendix A. General considerations should include the following:

- Identify the objectives of the study.
- Identify the chemicals of concern including parent and breakdown products.
- Identify possible preferential pathways.
- Establish the number, location and analytical method for soil gas samples to satisfy the plan objective including appropriate QA/QC protocols, such as leak testing, sample duplicates, and equipment blanks.
- Establish soil gas probe installation and sampling protocols.
- Determine if vertical profiles are needed to assess potential biodegradation/attenuation.
- Compare the concentrations of the chemicals of concern to the soil gas screening levels.

- Determine if the vapor intrusion pathway is a concern.

5.3 Field Screening

As part of any soil gas sampling plan, field screening should be conducted to evaluate potential preferential vapor migration pathways. The field screening survey should evaluate underground utilities such as water, sewer, gas, electric, and telecommunication lines as well as any foundation penetrations, such as sumps, into the structure(s) in the study area. Field screening should be conducted using either a photoionization detector (PID) or flame-ionization detector (FID) or other instrument appropriate for detecting the COC. As most field screening instruments have detection limits in the part per million range, use of these instruments will only provide an indication of gross contamination.

5.4 Soil Gas Probes

DES recommends active soil gas sampling for assessing the risk to human health as part of a vapor intrusion assessment and for use in comparison with the soil gas screening levels in Table 1. There are two methods used to collect active soil gas samples, where a vapor sample is collected from the vadose zone and then analyzed either at an off-site laboratory, or on-site in a mobile laboratory; temporary soil gas probes that are only sampled once or, permanent soil gas probes that can be sampled over time to account for expected ranges of conditions that may influence concentrations (i.e., seasonal, atmospheric, hydrogeologic, etc.).

Temporary vapor probes can be installed by making a hole with a slide hammer, then placing a sample probe in the pilot hole and sealing the annular space at the top of the rod with an inert impermeable material. Other temporary vapor probes use a retractable or removable drive tip. After the soil gas sample is collected the probe is removed.

Permanent soil gas probes typically consist of a small-diameter tube with a screen or sample port installed at the tip, or a small diameter well. Tubing/well diameter should be small, usually ranging from 1/4 to 1 inch to limit the amount of purge volume. The tube/well is installed to a specific depth in a bore hole created with a slide hammer, direct-push system or a hollow stem auger. Sand is installed in the annulus around the sampling port/well screen and the remainder of the bore hole is sealed with bentonite. The tubing/well is usually capped at the surface and the bore hole is completed with a well cover at ground surface.

Whether installing a temporary or permanent soil gas probe, a competent surface seal is necessary to prevent ambient air from diluting the soil gas sample. Figure 3 shows several types of soil gas probes and well material, and Figure 4 shows a schematic of a permanent soil gas probe.

The collection of sub-slab soil gas samples from directly beneath a building may provide a better indication of a possible vapor intrusion problem than soil gas samples collected beyond the building foot print; however, this sampling method is more intrusive to the building owner/occupant. When contemplating collection of sub-slab soil gas samples care must be taken not to damage the integrity of the slab. Coring through the slab can create a preferential pathway and therefore a proper seal is important when using this method. Figure 5 shows a schematic of a sub-slab soil gas probe.

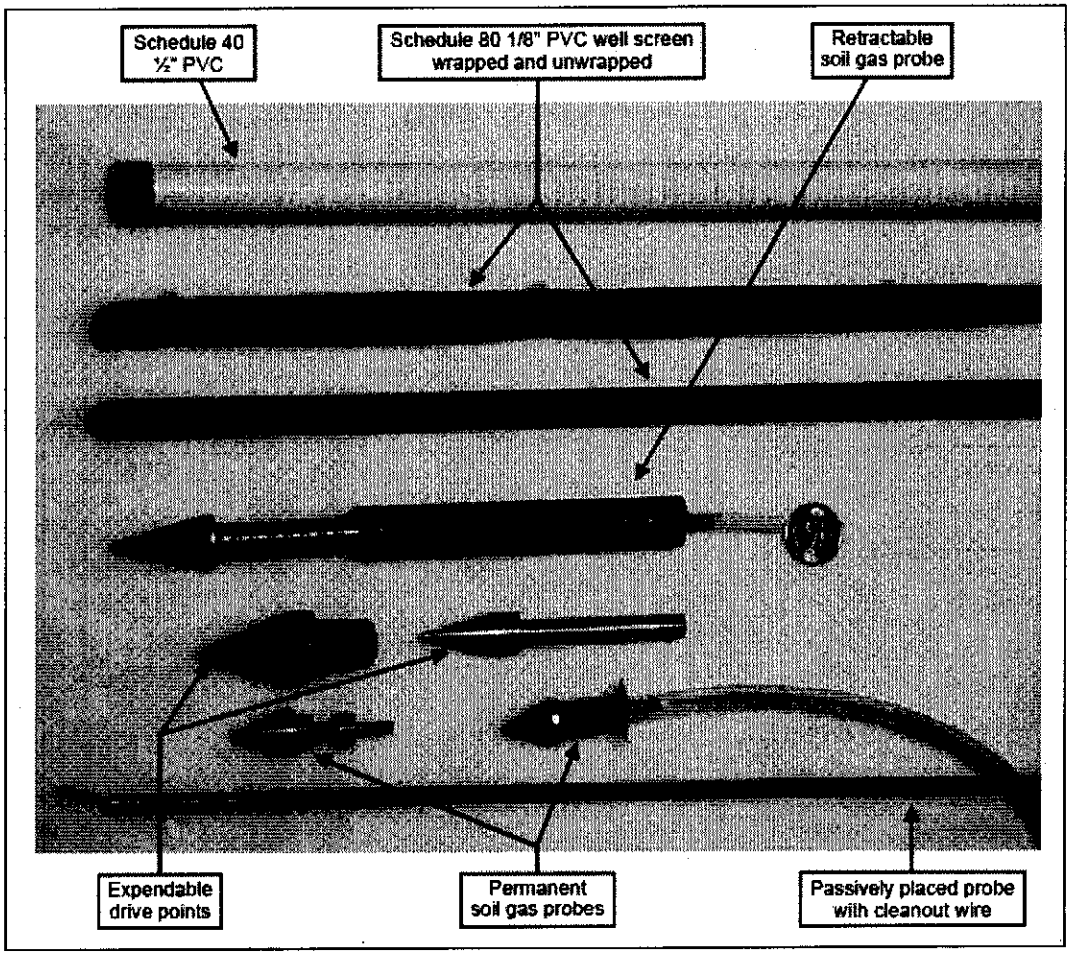


Figure 3 Soil Gas Sampling Probes (NJDEP 2005)

5.5 Sample Collection and Analysis

Soil gas samples should be collected at the location(s) suspected of having the highest vadose-zone contamination immediately adjacent (within 10 feet) to the structure(s) under investigation. Samples from the area immediately adjacent to a structure should be collected at a depth well below the base of the foundation. For residential structures with basements, DES recommends a depth of 10 feet below grade. In situations where shallow groundwater prevents this, other sampling procedures may be employed, including collection of sub-slab samples, or exterior soil gas samples from beneath large impervious surfaces where vapor may accumulate such as an adjacent driveway or parking lot. If collecting sub-slab soil gas samples directly beneath a building slab, groundwater should be at least 6 inches below the slab.

When conducting an exterior soil gas sampling program to evaluate vapor intrusion from a large VOC groundwater plume that may impact a significant number of structures, it may not be practical to collect exterior soil gas samples within 10 feet of each structure. For this scenario, the number, depth and location of soil gas samples should be adequate to conservatively delineate the subsurface soil gas plume, and identify structures that may be susceptible to vapor intrusion.

For undeveloped lots where future structures are planned, deep exterior soil gas samples may be used to assess the potential for vapor intrusion for the future use scenario planned. The number and depth of soil gas samples should be adequate to conservatively delineate concentrations in soil gas.

Short-circuiting of atmospheric air into the soil gas probe can result in diluted soil gas samples that under report actual subsurface soil gas concentrations for the COC. To ensure that valid soil gas samples are collected as part of a vapor intrusion assessment the use of a tracer compound can be used to assess for surface/annular seal leaks around the top of the soil gas probe.

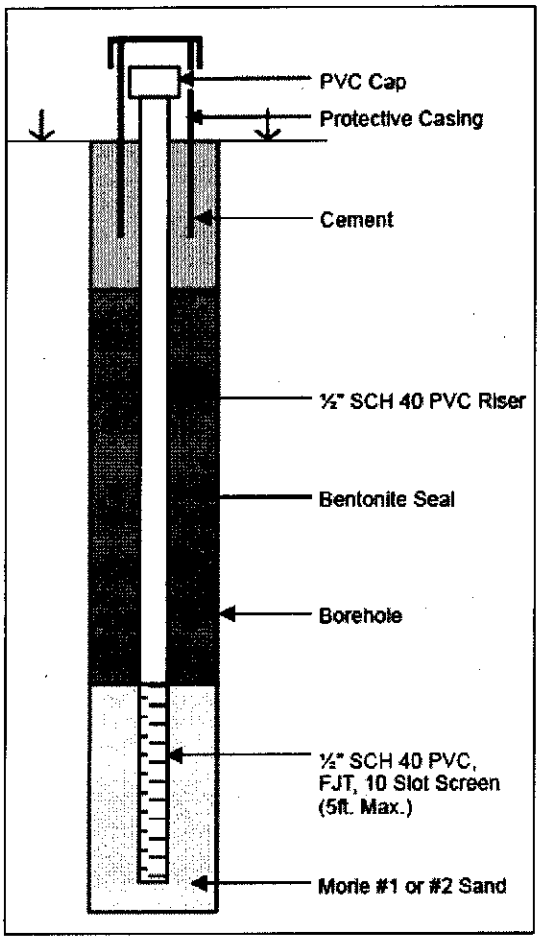


Figure 4 Permanent Soil Gas Probe (NJDEP 2005)

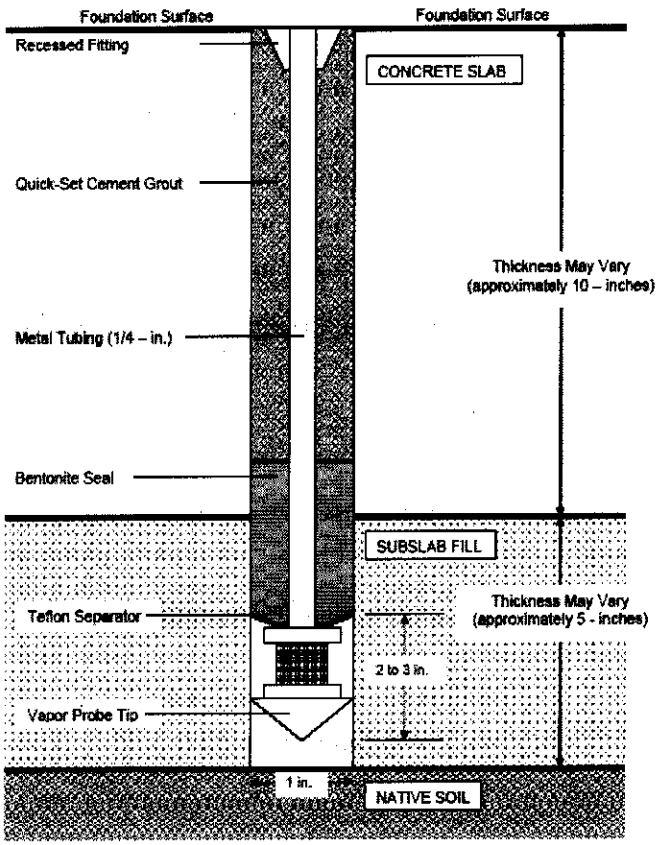


Figure 5 Sub-slab Soil Gas Probe (CAEPA DTSC 2004)

Depending on the nature of the contaminants of concern a number of different compounds can be used as a tracer. Sulfur hexafluoride (SF6) or helium are used as tracers because they are readily available have low toxicity and can be monitored with portable measurement devices. Iso-propanol, the main ingredient in rubbing alcohol, could also be used as a tracer but would require laboratory analysis for the tracer. In all cases the same tracer application should be used for all probes at any given site. The leak test should be conducted using a tracer that is not expected to be present in the soil gas being tested.

Because minor leakage around the probe seal should not materially affect the usability of the soil vapor sampling data the presence of low concentrations of the tracer gas in the sample may not be a major cause for concern. If elevated levels of tracer gas are observed in a sample, the soil gas data should not be considered reliable and the probe seal should be modified to reduce the infiltration of ambient air and the probe re-sampled. Portable field monitoring devices with detection limits in the low ppm range should be adequate for screening samples for tracer leak testing.

Potential short circuiting of atmospheric air during sampling can also be indirectly evaluated through examination of oxygen and carbon dioxide data collected from soil gas probes and ambient air. For example if oxygen concentrations at a probe installed within a petroleum hydrocarbon source area are at atmospheric levels the soil gas data should not be considered reliable and the probe seal should be modified and the probe re-sampled. DES recommends collecting oxygen and carbon dioxide data when conducting soil gas surveys to assess the vapor intrusion pathway. DES recommends using the Soil Gas Probe Field Data Report Form in Appendix B when conducting soil gas evaluations.

Prior to collecting the soil gas sample for analysis DES recommends a minimum of one to a maximum of five purge volumes be evacuated from the soil gas probe. The purge volume should be consistent for all samples collected from the study area. When purging or collecting samples using a vacuum pump or a canister the vacuum applied to the soil gas probe should be kept to the minimum necessary to collect the sample and the flow rate should not exceed 200 milliliters per minute. This should limit the potential for ambient air being drawn into the soil gas sample from the ground surface and it should limit desorbing of vapors from contaminated soils. Depending on the scope of the study and the data quality objectives, soil gas samples may be collected using gas-tight syringes, sorbent media, canisters or tedlar bags. Gas tight syringes and tedlar bags are appropriate when an on-site field laboratory is utilized and samples are analyzed immediately following sample collection. The following table provides a list of several soil gas analytical methods.

Method No.	Collection Device Methodology	Type of Compounds	Detection Limit Range
TO-1	Tenax solid sorbent GC/MS or GC/FID	VOC	0.02 – 200 ug/m^3 (0.01-100 ppbv)
TO-2	Molecular sieve sorbent GC/MS	VOC	0.2 – 400 ug/m^3 (0.1-200 ppbv)
TO-3	Cryotrap GC/FID	VOC	0.2 – 400 ug/m^3 (0.1-200 ppbv)
TO-13A	Polyurethane foam GC/MS	PAH	0.5-500 ug/m^3 (0.6 – 600 ppbv)
TO-15	Canister GC/MS	VOC (polar/nonpolar)	0.4 – 20 ug/m^3 (0.2-2.5 ppbv)
TO-17	Single/multi-bed adsorbent GC/MS FID	VOC	0.4 – 20 ug/m (0.2-2.5 ppbv)
8021B	Tedlar Bag Canister GC/PID	VOC	4.0 – 60.0 ug/m^3 (0.3 ppbv to 30 ppbv)
8260B	Tedlar Bag Canister GC/MS	VOC	10.0 – 50.0 ug/m^3 (0.6 ppbv to 25 ppbv)
8270C	Tedlar Bag Canister GC/MS	SVOC	1000 ug/m^3 (20000 ppbv to 100000 ppbv)

To maintain sample integrity:

- Maximum holding times for soil gas samples should not be exceeded.

- Soil gas samples should not be chilled during storage.

Soil gas samples should be analyzed for the appropriate COC including breakdown products as part of the vapor intrusion assessment. The analytical method used should be able to identify and quantify the target analytes and be capable of meeting the soil gas screening levels listed in Table 1. DES recommends that all soil gas analysis be done using gas chromatography. Soil gas sample results submitted to DES should be reported in units of ug/m^3. Soil gas sampling field data should be detailed on the Soil Gas Probe Field Data Report Form and submitted with the results.

5.6 Soil Gas Data Evaluation

The evaluation of soil gas data should determine if the pathway is likely complete or if additional data is needed to evaluate the pathway. A data quality evaluation should be completed to determine if the data is sufficient to be used for the pathway assessment, by reviewing tracer results and detection limits to determine data usability.

If the levels in soil gas below or immediately adjacent to a building are above the soil gas screening levels indicating that the indoor air pathway is likely complete future actions may include the following:

- Conduct additional soil gas sampling to develop a more complete understanding of the distribution of chemicals in soil gas.
- Conduct indoor air sampling to correlate soil gas levels to indoor air levels for COC taking in to account indoor air background levels.
- Implement abatement actions.
- Use additional investigative tools as described in Section 8.

If the concentrations of COC in soil gas at or near the building are below the soil gas screening levels and the data quality objectives are satisfactory then the vapor intrusion pathway may not be a concern; however, due to potential variability in soil gas concentrations, multiple soil vapor probes and multiple sampling events that cover the expected range of conditions that may influence concentrations (depth, seasonal, atmospheric, hydrogeologic, etc.) may be necessary.

6.0 INDOOR AIR SAMPLING

6.1 General Approach

There are inherent problems with sampling indoor air and also with interpreting the results. Indoor air sampling should be conducted after groundwater and/or soil gas data indicate the potential for vapor intrusion. Indoor air sampling may also be necessary under other circumstances including contaminated groundwater intrusion into buildings, before, during or after corrective actions have been taken, where preferential pathways exist that would limit the usefulness of groundwater or soil gas data, at residential fuel oil spill sites or where there are odor complaints.

When conducting indoor air sampling as part of a vapor intrusion pathway assessment there are several steps that should be taken into account.

- Define the study goals.
- Identify the COC including parent and breakdown products.
- Select number and location of sampling locations.
- Select duration of sampling event.
- Select sampling method with appropriate detection limit.
- Establish QA/QC requirements.

When contemplating indoor air sampling to assess large plumes that have the potential to impact a significant number of structures, DES recommends identifying primary and secondary structures for indoor air sampling. Conduct indoor air sampling at the primary structures first based on groundwater and exterior soil gas concentrations. Expand the scope of indoor air sampling to the secondary structures if some of the primary structures show vapor intrusion impacts. This investigative strategy, or "step-out process," should be conducted in a sequential manner until a perimeter of no impacts is defined.

6.2 Site Inspection, Product Inventory and Field Screening

Prior to collecting indoor air samples a site inspection should be conducted and a building inventory of potential VOC sources should be completed. Field screening of potential preferential pathways into the structure should also be conducted. The field screening survey should evaluate any foundation penetrations such as water, sewer, gas, electric and telecommunication lines, as well as sumps. In addition, field screening of potential VOC building sources should be conducted to determine if any products may be leaking VOC vapors into the building. Field screening should be conducted using either an FID or PID appropriate for detecting the COC.

6.3 Sample Collection and Analysis

When collecting indoor air samples, it is advisable to sample under conditions that are the most likely to represent conservative or worst case conditions (refer to Section 6.5). Samples should be collected from the lowest level of the structure where vapors are expected to enter (typically the basement or crawl space), a common area living space/work space on the first floor, and an outdoor location representative of background outdoor ambient air. DES recommends that indoor air samples be collected concurrent with soil gas samples, where appropriate, for a better understanding of the vapor conceptual model at a site.

DES recommends the collection of time integrated indoor air samples for risk assessment purposes as part of the vapor intrusion pathway assessment. The sample duration should be reflective of the site specific exposure scenario that represents the true time-integrated average concentration that an inhabitant may be exposed to. If evaluating low concentration long term exposure for a residential scenario, a 24-hour sample duration should provide a representative sample. For non residential sampling, such as a work place scenario, an 8-hour sampling duration may be more appropriate. Ideally the duration and frequency of sampling should cover the range of conditions that may influence concentrations (i.e., seasonal, atmospheric, hydrogeologic, etc.). For collection of time integrated samples for VOC analysis used for risk assessment purposes DES recommends the use of pre-evacuated stainless steel canisters.

The indoor air samples should be analyzed for the appropriate COC including breakdown products as part of the vapor intrusion assessment. The analytical method should be able to identify and quantify the target analytes and be capable of meeting the indoor air screening levels in Table 1. Laboratories performing low level air analysis should be able to demonstrate the ability to deliver acceptable results. DES recommends that laboratory analysis for VOCs be done using gas chromatography/mass spectrometry (GC/MS) and where appropriate using the high resolution selected ion monitoring (SIM) mode for low level detection. When conducting indoor air sampling the Indoor Air Sampling Form in Appendix C should be completed and sampling should be conducted in accordance with the Indoor Air Sampling Protocol in Appendix D. All indoor air sample results submitted to DES should be reported in units of ug/m^3. The following table provides a list of several indoor air analytical methods. For VOC analysis DES recommends EPA Method TO-15 including SIM mode where appropriate.

Method Reference	**Description**	**Types of Target Compounds**	**Detection Limit Range**
TO-4A	High Volume sampling PUF media GC/ECD analysis	Pesticides & PCBs	Pesticides: 0.5 –1 ug/sample PCBs: 1 – 2 ug/sample
TO-10A	Low Volume sampling PUF media GC/ECD analysis	Pesticides & PCBs	Pesticides: 0.5 –1 ug/sample PCBs: 1 – 2 ug/sample
TO-13A	High Volume sampling PUF/XAD media GC/MS analysis	SVOCs	5 – 10 ug/sample
TO-15LL	Canister collection GC/MS analysis	Non-Polar & Polar VOCs	0.5 – 3 ug/m^3
TO-15 SIM	Canister collection GC/MS (SIM mode) analysis	Low level VOCs	0.011 – 0.5 ug/m^3

TCE is a primary contaminant at many sites in NH and the toxicity of TCE is the subject of considerable debate. In 1989 EPA withdrew the TCE cancer toxicity values from its Integrated Risk Information System (IRIS) database. Since that time, EPA has come out with draft health information that TCE is suspected of being more toxic than previously thought. Due to the uncertainty associated with the toxicity of this chemical DES recommends that when conducting indoor air sampling for the vapor intrusion pathway where TCE is a COC, analysis be completed using selected ion monitoring (SIM) when appropriate, to achieve the lowest detection limit possible to determine if TCE is present in indoor air.

6.4 Background

There are two types of background associated with indoor air sampling, indoor air background and ambient outdoor background. Either may exceed the indoor air screening levels listed in Table 1. Although there is a simple way to measure ambient outdoor background it is difficult to reliably measure indoor air background. For these reasons collection of indoor air data without additional lines of evidence to indicate the potential for vapor intrusion from subsurface sources is not advised. Where vapor intrusion COC are expected to be present as background sources in a building, DES recommends collecting sub-slab soil gas samples concurrent with the collection of indoor air samples.

There have been several studies that have measured indoor air and ambient outdoor air background levels. The New York State Department of Health collected samples from 104 single family homes heated with fuel oil between 1997 and 2003. More than 600 samples were collected from basements, living spaces and outdoor ambient air. The US EPA Building Assessment and Survey Evaluation (BASE) study was conducted on 100 public and commercial office buildings between 1994 and 1998. The 25th to 75th percentile range of concentrations from these two studies have been summarized in the Table below for some of the more common VOCs detected in groundwater at contaminated sites. Units are in $\mu g/m^3$.

Compound	NYSDOH Study (1997-2003)		EPA BASE Data (1994-1998)	
	Residential Single Family Homes		Commercial Office Buildings	
	Indoor	Outdoor	Indoor	Outdoor
Trichloroethane, 1,1,1-	<0.25 – 1.1	<0.25 – 0.38	2.6 – 11	<0.6 – 1.7
Dichloroethane, 1,2-	<0.25	<0.25	<0.6	<0.6
Trimethylbenzene, 1,2,4-	0.69 – 4.3	<0.25 – 0.81	1.7 – 5.1	<1.6 – 3.1
Trimethylbenzene, 1,3,5-	<0.27 – 1.7	<0.25 – 0.34	<1.5	<1.4
Benzene	1.1 – 5.9	0.57 – 2.3	2.1 – 5.1	1.2 – 3.7
Ethylbenzene	0.41 – 2.8	<0.25 – 0.48	<1.6 – 3.4	<1.4 – 1.6
Methylene chloride	0.31 – 6.6	<0.25 – 0.73	<1.7 – 5.0	<1.8 – 3.0
Xylenes (m&p)	0.50 – 4.6	<0.25 – 0.48	4.1 – 12	<3.6 – 7.3
Methyl-tert-butyl-ether	<0.25 – 5.6	<0.25 – 0.86	<1.7 - 12	<1.8
Tetrachloroethylene	<0.25 – 1.1	<0.25 – 0.34	<1.9 – 5.9	<1.4 – 3.0
Toluene	3.5 – 24.8	0.61 – 2.4	10.7 - 26	5.9 - 16
Trichloroethylene	<0.25	<0.25	<1.2 – 1.2	<1.5
Vinyl chloride	<0.25	<0.25	<0.9	<1.0

To minimize the impact of indoor air background for residential sampling, indoor activities such as smoking, use of sprays, solvents, paints, etc., should be suspended immediately prior to and during sampling. Outdoor activities that could influence indoor air levels such as mowing, painting, and asphalting, should also be suspended during sampling.

6.5 Sampling under Conservative Conditions

Sampling under conservative conditions is a matter of where and when the samples are collected. Conservative samples are generally located in the basement or lowest portion of the building (crawl space) where vapors first enter a structure. Conservative samples would also be defined under certain ambient conditions as noted below.

Parameter	Most conservative	Least conservative
Season	Late winter/early spring	Summer
Temperature	Indoors 10^0F greater than outdoors	Indoor temp. less than outdoor
Wind	Steady greater than 5 mph	Calm
Soil	Saturated with rain	Dry
Doors/Windows	Closed	Open
Mechanical Heating System	Operating	Off
Mechanical fans	Off	On

Modified from Massachusetts Indoor Air Sampling and Evaluation Guide (2002)

6.6 OSHA Considerations

The Occupational Safety and Health Act of 1970 (OSHA) uses permissible exposure limits (PELs) to regulate work place exposure to chemicals. OSHA PELs are based not only on risk but are adjusted to account for factors including economic feasibility. PELs are different than the DES indoor air screening levels, which have been established for chemicals that are released to the environment and are generally based on risk exposure criteria. For most of the identified VOCs in Table 1 the DES indoor air screening levels are well below the established OSHA PELs.

The following examples illustrate where OSHA PELs would apply or where the use of this guidance would be more appropriate to evaluate exposures due to vapor intrusion at contaminated sites.

- If an industrial worker is exposed to vapors from a subsurface source of contamination regulated by DES (regardless of whether that contamination is derived from that facility or another) and are simultaneously exposed to the same hazardous vapors in the work place and is knowledgeable of their exposures then the exposure would be regulated under OSHA.

- If an industrial worker is exposed to vapors from subsurface contamination and exposed to different hazardous chemicals in the work place that they protect themselves against but not those associated with the subsurface contamination then the exposure associated with the release may be managed in accordance with this guidance. The employer has the option of incorporating the additional environmental exposure into their employee protection program in which case OSHA requirements would apply.

- If a worker is exposed to vapors from subsurface contamination that is not associated with the normal operating conditions of that work place, such as a commercial office building, restaurant or daycare center, then the employee's exposure may be managed in accordance with this guidance.

In general, DES recommends using this guidance where employees within buildings have not voluntarily accepted a risk associated with environmental contamination in connection with their employment. This can include buildings located at the spill site, and properties down gradient of the spill site.

7.0 EVALUATION OF RESULTS

When conducting a vapor intrusion investigation, the goals are to determine if vapor intrusion is occurring, and if so is mitigation necessary to protect building occupants. Once all the analytical results have been collected the data should be compared to the appropriate screening levels. DES recommends a multiple line of evidence approach when evaluating the vapor intrusion pathway.

Groundwater data should be evaluated to determine if the extent of the VOC plume has been adequately delineated. Groundwater data should be compared with the GW-2 groundwater screening values, and all buildings within 100 feet horizontally (30 feet for petroleum hydrocarbons) of groundwater that exceeds the screening levels should be identified for further evaluation.

Once groundwater data indicates the potential for vapor intrusion an exterior soil gas sampling program should be conducted to delineate the extent of the subsurface vapor plume. The results of exterior soil gas sampling should then be compared with the appropriate soil gas screening levels. Where soil gas samples do not exceed the screening levels, but groundwater exceeds the screening levels, a site specific evaluation is recommended to determine if vapor intrusion may be ruled out. This evaluation would require an understanding of the site conceptual model and should take into consideration the following:

- Shallow groundwater concentrations will not likely increase in the future.
- Site conditions at the time of soil gas sampling are not likely to result in higher soil gas concentrations due to seasonal, atmospheric, hydrogeologic, or other reasons.

Due to the potential for variability in soil gas concentrations, DES does not recommend the averaging of soil gas samples. Each data point should be evaluated separately. Where groundwater exceeds the GW-2 screening levels, DES recommends that a minimum of two rounds of exterior soil gas data be collected to rule out vapor intrusion as a potential exposure pathway due to potential variability in soil gas concentrations. If exterior soil gas samples exceed the screening values then additional investigation of the vapor intrusion pathway may consist of collecting indoor air samples from structures that may be at risk of vapor intrusion.

Determining if there is an exceedance of the indoor air screening levels attributable to vapor intrusion can be difficult. When reviewing indoor air data as part of a vapor intrusion pathway assessment it is important to distinguish between background VOCs in indoor air from VOCs determined to be the result of vapor intrusion. A few examples are illustrated below:

- Compare the relative concentration of COC at different locations in a structure;

  If the ratio of benzene to xylene in the basement is 1:1 and there is three times as much xylene as benzene on the first floor there is probably a background source of xylene located on the first floor.

- Evaluate concentration gradients of contaminants of concern within a structure.

  If the concentration of a contaminant is highest in the basement and decreases as you move up to the first and second floors vapor intrusion may be the primary source. If the concentrations are higher in the upper floors than the basement a background source unrelated to vapor intrusion is probably located in the structure and may be the primary source.

- Compare sub-slab soil gas data to indoor air data.

  Contaminants detected in indoor air that are not detected in sub-slab samples indicates there is likely a background source unrelated to vapor intrusion. If a concentration gradient exists where sub-slab concentrations are higher than indoor air concentrations of COC this is an indication that vapor intrusion is occurring that may warrant further evaluation, abatement or continued monitoring.

As illustrated above when developing the conceptual vapor migration model for a site and determining contributions from background, sub-slab soil gas data combined with indoor air data can be helpful particularly when COC are likely to be present from background sources not related to vapor intrusion. In some instances it may be more economical to mitigate an anticipated vapor intrusion exposure than to conduct rigorous indoor air testing.

If indoor air sampling indicates there is no exceedance of the indoor air screening levels then further evaluation of the pathway may not be necessary, however, multiple sampling events may be necessary to rule out vapor intrusion as a pathway of concern.

If the levels in indoor air exceed the indoor air screening levels as a result of vapor intrusion, abatement measures and/or continued monitoring or further assessment may be warranted.
Further assessment may consist of a site specific health risk assessment. A site specific health risk assessment should demonstrate that the contribution of VOCs from vapor intrusion is not presenting a significant risk to building occupants. The frame work for conducting a site specific health risk assessment for the vapor intrusion pathway is presented in Appendix E.

8.0 ADDITIONAL INVESTIGATIVE TOOLS

There are a number of different tools available to evaluate VOC vapor migration as part of a site specific vapor intrusion assessment or simply to aide in the understanding of the vapor conceptual site model.

8.1 Determination of a Site-specific Soil Gas Attenuation Factor

Measurement of a conservative tracer inside of a structure and in the sub-slab soil gas below a structure can be used to determine a site-specific soil gas attenuation factor. The calculated site-specific soil gas attenuation factor may then be used to estimate the indoor air concentration of the COC from a measured sub-slab soil gas concentration. This method assumes that all sub-slab vapor phase contaminants are entering the building at equal rates. Naturally occurring radon is a commonly used conservative tracer. If sub-slab samples are being collected concurrent collection of radon may be useful especially if the potential exists for indoor air background levels of the COC.

8.2 Indoor/sub-slab Differential Pressure Measurements

Measurement of the pressure gradient between the sub-slab and overlying structure can assist in interpreting the direction of vapor transport, whether into or out of the structure. If the building is over-pressured relative to the sub-slab, measured indoor concentrations might be more likely attributed to above-ground sources from within the building. Conversely if the building is under-pressured relative to the sub-slab, measured indoor concentrations might be more likely attributed to below-ground sources associated with vapor intrusion. Differential pressure measurements are easy and inexpensive, and can be collected continuously around the clock. The success of this approach may require multiple indoor air measurements to establish long term patterns.

8.3 Passive Soil Gas

DES considers passive soil gas sampling as a qualitative tool. Sampling devices which house an adsorbent material are placed in the subsurface and left to collect vapors over several days. VOCs migrating through the subsurface are colleted onto the adsorbent material. The sampling devices are then retrieved and analyzed. Passive soil gas sampling can be an effective tool in understanding the composition and the location of subsurface vapor plumes. DES does not recommend using passive soil gas samples for quantifying contaminant concentrations in soil gas and therefore should not be used for comparison with the soil gas screening levels listed in Table 1.

Passive soil gas sampling methods can be used to collect soil gas from low-permeability and high moisture settings where conventional active soil gas sampling may be problematic. Passive soil gas sampling methods are capable of detecting compounds present in very low concentrations. Passive soil gas samplers can be placed into potential preferential vapor migration pathways such as utility corridors and foundation cracks to determine if these pathways are acting as significant VOC migration pathways into a structure.

8.4 Flux Chamber

Flux chambers are enclosures that are placed directly on a surface for a few hours to a few days, and the resulting contaminant concentration in the enclosure is then measured which yields the contaminant flux at a surface.

Flux chambers are a qualitative tool that can be used to locate surface fluxes of VOC contamination and entry points into structures. Flux chambers may be suitable for structures with dirt floors, larger slabs in good condition, and for future use scenarios on undeveloped land. Specialized equipment and experienced staff is necessary when conducting flux chamber evaluations.

8.5 Modeling

Modeling can assist in evaluating the potential for vapor intrusion from subsurface contamination. One of the most common vapor intrusion models is the Johnson and Ettinger (J/E) model used by EPA. The J/E vapor transport model was originally developed by P. Johnson and R. Ettinger in 1991 and has subsequently been modified by EPA. The J/E model is based on the basic principles of contaminant fate and transport, contaminant partitioning between media and the physical and chemical properties of the contaminants. The model incorporates both diffusion and advection as mechanisms of transport of subsurface vapor into the indoor air environment. The J/E model is based on the following assumptions:

- Steady-state conditions.
- Infinite source of contamination.
- Homogeneous subsurface.
- Uniform air mixing in the structure.
- No preferential pathways.
- No biodegradation.
- Homogeneous distribution of contaminants.

- Contaminant vapors enter structure through cracks in the foundation and walls.
- Structures are slab-on-grade or have basements.
- Ventilation rates and pressure differences are assumed to remain constant.

Using a range of potential input parameters the model can predict a wide range of indoor air impacts spanning orders of magnitude. When using the J/E model, input parameters for a given site should match site-specific conditions. It is important to understand the sensitivity of the input parameters on the results of the model and therefore DES recommends that vapor intrusion evaluations that involve modeling include a sensitivity analysis.

9.0 VAPOR INTRUSION ABATEMENT STRATEGIES

When evaluation of the vapor intrusion pathway shows that vapor intrusion is a concern, abatement strategies can eliminate or mitigate the potential exposure pathway. Strategies for abating vapor intrusion involve both passive and active techniques. A combination of strategies may be most effective. Techniques can include the following:

- Sealing of cracks, utility conduits, sumps etc. in the basement, or crawl space.
- Passive Barriers, i.e. thin plastic liners, heavy HDPE liners, spray on elastomers, etc.
- Sub slab depressurization (SSD), or radon system.
- Natural ventilation.
- Heating recovery ventilation.
- Building pressurization.
- Soil pressurization.
- Indoor air treatment.

If passive techniques are insufficient to limit risk a more active technique may be necessary to prevent the entry of contaminant vapors into a building.

The most common technique for eliminating the vapor intrusion pathway for a residential structure is the installation of a SSD system. This technique has been used for many years to eliminate radon vapor issues. The system works by depressurizing the soil beneath the building envelope thus creating a negative pressure zone that becomes a "sink" for the contaminated vapors. The contaminated vapors are collected and discharged to ambient air typically above the building's roof line. SSD systems can be used in buildings with a basement, crawl space or slab-on-grade foundation. If the floor of the basement or crawl space is dirt, a membrane/vapor barrier must be placed and sealed to the foundation wall as part of the overall system. Figure 5 shows a schematic of a residential SSD system. SSD systems have been successful in reducing the health risks associated with vapor intrusion for building occupants.

The components of a typical residential SSD system include: an extraction pit beneath the slab or membrane, PVC piping and a blower. A couple of important considerations prior to installation of the SSD system are that groundwater should be more then 6 inches below the foundation and that all entry points such as cracks in the foundation floor and walls and sumps must be sealed.

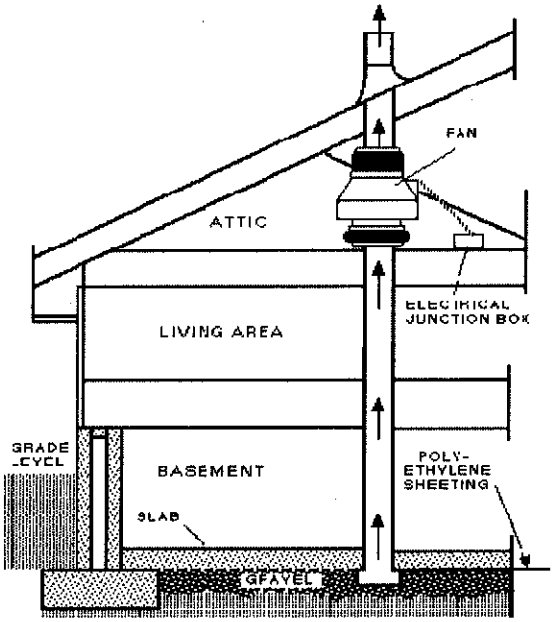


Figure 6 Sub slab Soil Depressurization System (EPA April 2001)

When designing an SSD system there are other considerations. A visible or audible alarm may be desirable to indicate when a loss of system pressure has occurred. The possibility of back drafting occurring in the system should also be considered. This is especially important in buildings with heating systems that vent combustion gases to the ambient air.

DES recommends that SSD systems be designed and installed by professionals with prior experience with these type of radon systems and preferably are certified by either the National Environmental Health Association or the National Radon Safety Board. All designs should have site specific performance standards along with a plan to monitor these standards.

For proposed buildings that are to be constructed over a VOC source that has the potential to cause vapor intrusion, DES recommends at a minimum that a passive venting system be installed, that can be modified to an active system at a later date if necessary.

10.0 REFERENCES

American Petroleum Institute. October 2004. "Collecting and Interpreting Soil Gas from the Vadose Zone: A Practical Strategy for Assessing the Subsurface-Vapor-to-Indoor-Air Migration Pathway at Petroleum Hydrocarbon Sites." Final Draft.

California Environmental Protection Agency Department of Toxic Substance Control. (CAEPA DTSC) December 15 2004. "Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air."

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

DeVaull G.E. R.A. Ettinger J.P. Salanitro and J.B. Gustafson. 1997. Benzene toluene ethylbenzene and xylenes [BTEX] degradation in vadose zone soils during vapor transport: First-order rate constants. Proceedings of the petroleum hydrocarbons and organic chemicals in groundwater conference: Prevention detection and remediation. November 12-14 1997 Houston TX. Ground Water Publishing Company Westerville Ohio 365-379.

Fitzpatrick Nancy A and John J. Fitzgerald. October 1996. "An Evaluation of Vapor Intrusion into Buildings through a Study of Field Data." Massachusetts Department of Environmental Protection

Folkes D.J. "Design Effectiveness and Reliability of Sub-Slab Depressurization Systems for Mitigation of Chlorinated Solvent Vapor Intrusion." Presented at USEPA Seminars on Indoor Air Vapor Intrusion. December 2002. January 2003. February 2003. USEPA Office of Research and Development.

Hartman Blayne. October 2002. "How to Collect Reliable Soil-Gas Data for Risk-Based Applications Part 1: Active Soil-Gas Method." LUSTLine Bulletin 42.

Hartman Blayne. November 2004. "How to Collect Reliable Soil-Gas Data for Risk-Based Applications Part 3: Answers to Frequently Asked Questions." LUSTLine Bulletin 48.

Interstate Technology Regulatory Council Brownfields Team. December 2003. "Vapor Intrusion Issues at Brownfield Sites."

Johnson P.C. May 2002. "Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model." American Petroleum Institute Technical Report.

Massachusetts Department of Environmental Protection. December 1995. "Guidelines for the Design Installation and Operation of Sub-Slab Depressurization Systems." Northeast Regional Office.

Massachusetts Department of Environmental Protection (MADEP). April 2002. "Indoor Air Sampling and Evaluation Guide." Office of Research and Standards.

New Jersey Department of Environmental Protect (NJDEP). August 2005. "Field Sampling Procedures Manual."

New York State Department of Health. 1997-2003. "Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes" revised November 14, 2005.

Roggemans S. C.L. Bruce and P.C. Johnson. December 2001. "Vadose Zone Natural Attenuation of Hydrocarbon Vapors: An Empirical Assessment of Soil Gas Vertical Profile Data." American Petroleum Institute Technical Report.

United States Environmental Protection Agency (USEPA) 2001. Building Assessment and Survey Evaluation (BASE) Database. Washington DC: Office of Air and Radiation.

USEPA. April 2001. "Building Radon Out – A step by step Guide on How to Build Radon Resistant Homes." EPA 402-K-01-002.

USEPA January 1999. "Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air Second Edition." EPA/625/R-96/010b.

USEPA October 1993. "Radon Mitigation Standards," EPA 402-R-93-078. Revised April 1994.

USEPA. October 1993. "Radon Reduction Techniques for Existing Detached Houses: Technical Guidance for Active Soil Depressurization Systems 3rd Edition." EPA/625/R-93/011.

USEPA 2002. "OSWER Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)." Draft

USEPA. "Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations." Draft. Dominic DiGiulio Ph.D. Office of Research and Development. National Risk Management Research Laboratory. Ground-Water and Ecosystem Restoration Division Ada Oklahoma.

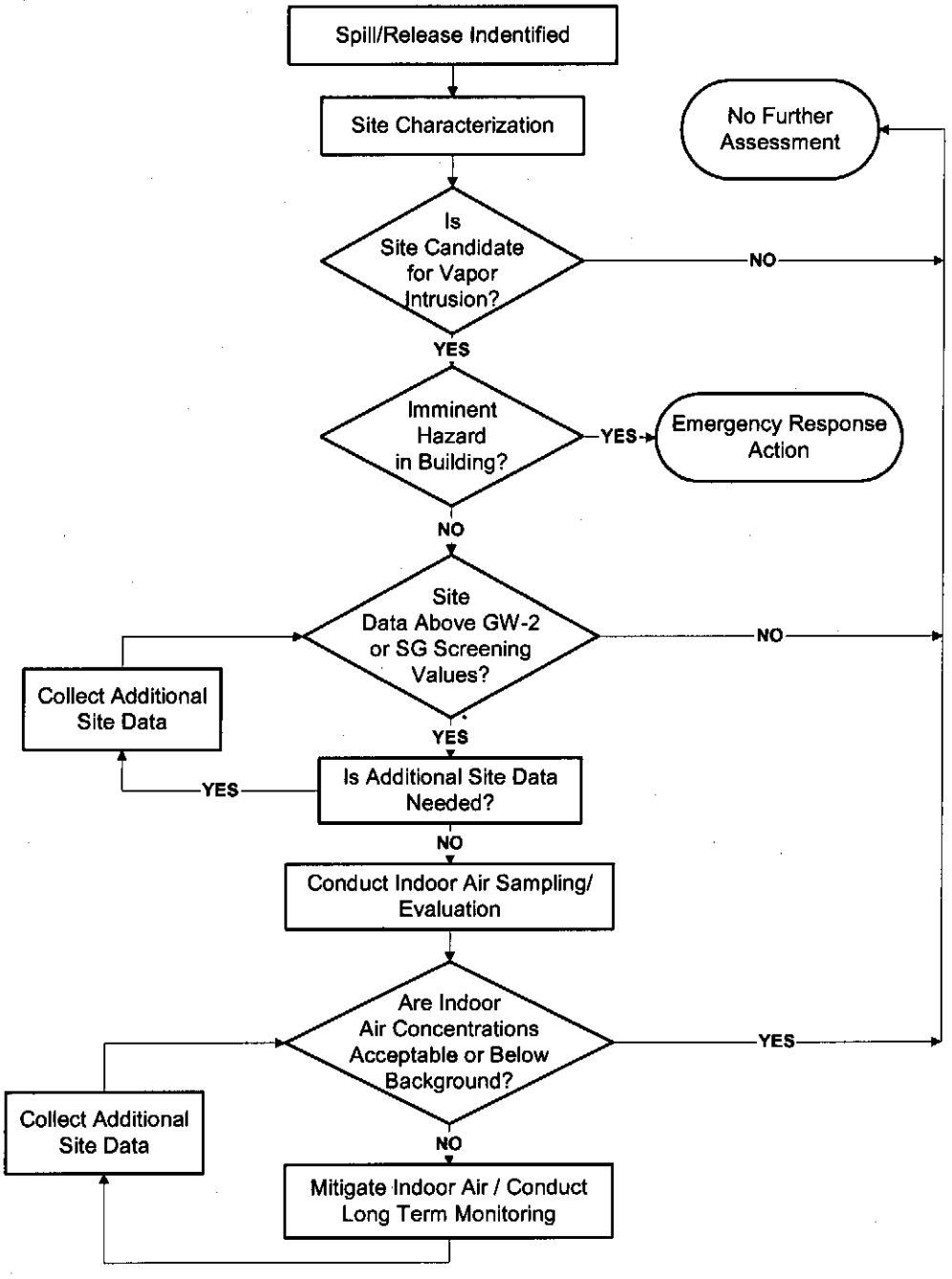
New Hampshire Department of Environmental Services
Waste Management Division Site Remediation Programs

Table 1
Vapor Intrusion Screening Levels

Chemical	Residential Indoor Air Screening Levels (µg/m³)	Commercial Indoor Air Screening Levels (µg/m³)	Residential Soil Gas Screening Levels (µg/m³)	Commercial Soil Gas Screening Levels (µg/m³)	Groundwater to Indoor Air Screening Levels GW-2(1) (µg/L)
Benzene	1.9(2)	1.9(2)	95	95	2,000
Bromoform	2.4	11	120	550	2,000
Bromomethane	1.0	1.5	50	73	10
Carbon Tetrachloride	1.3(3)	1.3(3)	63	63	40
Chlorobenzene	12	18	600	880	3,000
Chloroform	1.0(3)	1.0(3)	49	49	200
Dichlorobenzene, 1,2-	40	58	2000	2900	20,000
Dichlorobenzene, 1,4-	160	230	8000	12000	50,000
Dichloroethane, 1,1-	100	150	5000	7300	10,000
Dichloroethane, 1,2-	0.8(3)	0.8(3)	40	40	300
Dichloroethylene, 1,1-	40	58	2000	2900	1,000
Dichloromethane (Methylene Chloride)	5.6(2)	26	280	1300	1,000
Dichloropropane, 1,2-	0.9(3)	1.2	46	59	200
Ethylbenzene	200	290	10000	15000	50,000
Ethylene dibromide	1.5(3)	1.5(3)	77	77	700
Methyl ethyl ketone	1000	1500	50000	73000	50,000
Methyl isobutyl ketone	600	880	30000	44000	50,000
Methyl tert butyl ether (MTBE)	5.6(2)	15	280	770	10,000
Naphthalene	2.6(3)	2.6(3)	130	130	2,000
Styrene	200	290	10000	15000	50,000
Tetrachloroethane, 1,1,2,2-	1.4(3)	1.4(3)	69	69	1,000
Tetrachloroethylene (PCE)	1.4(3)	2.1	68	100	80
Toluene	1000	1500	50000	73000	50,000
Trichlorobenzene, 1,2,4-	3.7(3)	3.7(3)	190	190	1,000
Trichloroethane, 1,1,1-	440	640	22000	32000	20,000
Trichloroethane, 1,1,2-	1.1(3)	1.1(3)	55	55	500
Trichloroethylene (TCE)	1.1(3)	1.1(3)	54	54	50
Trimethylbenzene, 1,2,4-	4.3(2)	4.3(2)	220	220	3,000
Trimethylbenzene, 1,3,5-	1.7(2)	1.8	85	88	1,000
Vinyl chloride	0.5(3)	2.8	26	140	10
Xylenes (mixed isomers)	20	29	1000	1500	30,000

(1) Revised Risk Characterization and Management Policy GW-2 values.
(2) The screening values for these compounds are based on published background values.
(3) The risk based levels for these compounds are below the EPA TO-15 low level reporting limit and therefore the screening value is based on method reporting limit.

Figure 2 - Evaluating the Vapor Intrusion Pathway



APPENDIX A
New Hampshire Department of Environmental Services
Waste Management Division
Site Remediation Programs

Vapor Intrusion Conceptual Site Model Checklist

To assist in the development of the site-specific vapor intrusion conceptual site model, and/or planning a soil gas sampling survey, for a site, the following information should be compiled:

Utilities and Process Piping

☐ Identify on a site plan all underground utilities near the soil or groundwater impacts; pay particular attention to utilities that connect impacted areas to occupied buildings.

☐ Identify on a site plan all underground process piping near the soil or groundwater impacts.

Buildings

☐ Identify on a site plan all existing and planned future buildings under investigation.

☐ Identify the occupancy and use of each building (e.g., residential, commercial)

☐ Describe building construction materials (e.g., wood frame, block,), openings (e.g., windows, doors), and height (e.g., one-story, two-story, multiple-story); identify if there is an elevator shaft in the building.

☐ Describe building foundation construction including:

- Type (e.g., basement, crawl space, slab on grade)
- Floor construction (e.g., concrete, dirt)
- Depth below grade.

☐ Describe the building HVAC system including:

- Furnace/air conditioning type (e.g., forced air, radiant)
- Furnace/air conditioning location (e.g., basement, crawl space, utility closet, attic, roof)
- Source of return air (e.g., inside air, outside air, combination)
- System design considerations relating to indoor air pressure (e.g., positive pressure is often the case for commercial buildings).

☐ Identify sub-slab ventilation systems or moisture barriers present on existing buildings.

Source Area

☐ Identify the COC's related to the vapor intrusion pathway.

☐ Describe the distribution and composition of any NAPL at the site.

☐ Identify on a site plan all source areas for the COC's related to the vapor intrusion pathway.

☐ Identify on a site plan soil and groundwater results for the COC, between the source area and the

buildings under investigation.

- ☐ Identify on a geologic cross section soil and groundwater results including depth.
- ☐ Describe the potential migration characteristics (e.g., stable, increasing, decreasing) for the distribution of COC.

Geology/Hydrogeology

- ☐ Review all boring logs and soil sampling data to understand the locations of:
  - Sources: NAPL, soil, groundwater, suspected vapor leaks.
  - Soil types:
    - Finer-grained soil layers
    - Higher-permeability layers that may facilitate vapor migration.
- ☐ Identify on a geologic cross section distinct strata (soil type and moisture content – e.g., "moist," "wet," "dry") and the depth intervals between the vapor source and ground surface, and include the depth to groundwater.
- ☐ Describe groundwater characteristics (e.g., seasonal fluctuation, hydraulic gradient).

Site Characteristics

- ☐ Estimate the distance from GW-2 groundwater concentration contour interval for each COC to buildings under investigation.
- ☐ Estimate the distance from vadose zone source area to buildings under investigation.
- ☐ Describe the surface cover between the vapor source and buildings under investigation.

APPENDIX B
New Hampshire Department of Environmental Services
Waste Management Division
Site Remediation Programs

Soil Gas Probe Field Data Report							
Site:							
Date:							
Instrument(s) used:							
Tracer used:							
Weather:							
Technician:							
Soil Gas Probe Number	**Probe Depth (ft.)**	**Probe Volume (l)**	**Purge Rate (lpm)**	**Volume Purged (l)**	**Tracer Field Analysis (ppm)**	**%CO_2**	**%O_2**

ND=Non Detect
NM=Not measured

APPENDIX C
New Hampshire Department of Environmental Services
Waste Management Division
Site Remediation Programs

Indoor Air Sampling Form

DES Site # _____

DES Site Name _____

Address _____

_____

Occupant Information

Name _____

Address _____

_____

Telephone No (H) (___)_____

(W) (___)_____

Number and Age of Occupant_____

Does anyone smoke inside the building? _____

Building Characteristics

Type of building: (circle) Residential/Industrial/School/Commercial/Multi-use/Other? _____

If residential, what type (circle) Single family/Condo/Multi-family/Other?_____

If the property is commercial, indicate the business ? _____

How many floors does the building have? _____

Does the building have a (circle) Basement/Crawl space/Slab-on-grade/Other? _____

Is the basement used as a living/work space area?_____

What type of foundation does the building have (circle) Field stone/Poured concrete/Concrete block /Other?_____

Describe the heating system and type of fuel used?_____

Is there an attached garage? _____

Spill/Contaminant Source Information

Type of petroleum/VOC release? _____

When did the release occur? _____

What areas of the building have been impacted by the release? _____

Are there any odors? _____ If so describe the odors: _____

Where can release odors be detected? _____

Sampling Information

Sampling Date _____

Sampler Type Sorbent SUMMA (Please circle one)

Analysis Method TO-4A TO-10A TO-13A TO-15LL TO-15-SIM Other:_ (Please circle one)

Consulting Firm _____

Contact Person _____

Telephone No (___)_____

Laboratory _____

Telephone No (___)_____

Table 1: Sorbent Tube Sampler Information

Sample ID#	Floor	Room	Tube ID#	Pump ID#	Volume (liters)	Duration (minutes)	Comments

Table 2: Canister Sampler Information

Sample ID#	Floor	Room	Canister ID#	Initial On-site Pressure*	Pressure* On-site Following Sample Collection	Pressure Received at the Laboratory

* Indicate pressure in units of inches of mercury.

Please provide a sketch of spill area and location of sampler unit(s).

Pre-Sampling Inspection and Product Inventory

List products or items which may be considered potential sources of VOCs such as paint cans, gasoline cans, gasoline powered equipment, cleaning solvents, furniture polish, moth balls, fuel tank, woodstove, fireplace, etc.

Date and time of pre-sampling inspection _____

Table 3: Pre-sampling Inspection Product Inventory

Potential VOC source	Present (Y/N)	Location	Field screening Results (ppm)	Product Condition
Paints or paint thinners				
Gas powered equipment				
Gasoline storage cans				
Cleaning solvents				
Furniture polish				
Moth balls				
Fuel tank				
Wood stove				
Fireplace				
Perfumes/colognes				
Other:				
Other:				
Other:				

Table 4: Potential vapor migration entry point information

Potential Vapor entry points	Present (Y/N)	Field screening results (ppm)	Comments
Foundation penetrations in floor or walls			
Cracks in foundation floor or walls			
Sump			
Floor drain			
Other			
Other			

Was the building aired out prior to sample collection?_____
How long was the airing out process? _____

Were vapor control methods in effect while the samples were being collected?

Windows open? Yes / No Ventilation fans? Yes / No Vapor barriers? Yes / No

Vapor phase carbon treatment system? Yes / No Other site control measures_____

Weather Conditions during Sampling

Outside temperature (°F) _____ Inside temperature (°F)_____

Prevailing wind speed and direction _____

Describe the general weather conditions (e.g. sunny, cloudy, rain) _____

Significant precipitation (0.1 inches or more) within 12 hours of the sampling event? _____

General Comments

Is there any information you feel is important related to this site and the samples collected which would facilitate an accurate interpretation of the indoor air quality?

_____

APPENDIX D
New Hampshire Department of Environmental Services
Waste Management Division
Site Remediation Programs

Indoor Air Sampling Protocol

Introduction

Indoor air sampling for specific volatile organic compounds (VOC) can be performed to assist in determining if a contaminant is adversely affecting indoor air quality in a building. In general, certain conditions should be met and certain procedures should be followed to ensure integrity of the test results and to limit variables that may effect the success and interpretation of the data. This protocol is intended to ensure that air sampling data is collected in a consistent and useful manner during corrective action. The protocol outlines the steps to be followed when conducting indoor air sampling for VOCs in a residential setting however it may be modified for use in other situations. The resulting data obtained will provide a conservative indication of health risks posed to building occupants; however DES understands that under emergency response actions it may not be appropriate to complete the 24-hour pre-sampling inspection procedures outlined below. DES recommends that an indoor air sampling work plan be submitted to the department for comment prior to sampling unless the sampling is being conducted as part of an emergency response action.

Pre-sampling Inspection

A pre-sampling inspection and product inventory should be performed prior to sampling in order to characterize the structure layout and physical conditions of the home under evaluation. DES recommends completing the pre-sampling inspection 24 hours prior to sampling. In addition the inspection will allow for the identification of potential interfering sources of VOCs that may make data interpretation difficult. If the target VOCs are petroleum-related, interfering sources can include gasoline cans, gasoline powered equipment, paints and cleaning supplies containing petroleum distillates. If the target VOC is non-petroleum, such as tetrachloroethylene, other products or conditions that may be sources of these compounds, such as recently dry cleaned clothes, should be identified. Removing potential sources of VOCs from the indoor environment prior to testing is the most effective means of reducing interferences. If potential interferences can not be eliminated prior to sample collection it may make data interpretation more difficult. Field screening of potential sources may help to document if the sources are contributing to indoor air VOC concentrations and may help determine which sources should be removed prior to sampling.

If interfering sources are removed, DES then recommends ventilation of the building prior to testing to eliminate residual contamination from the interfering sources. The house should be ventilated by opening windows and doors for a period of 10 to 20 minutes. DES does not recommend building ventilation where no interfering VOC sources are observed or if potential VOC sources can not be removed from the building. The inability to eliminate potential interferences may be justification for not sampling. The primary objective of the indoor air test is to obtain a representative sample that provides a conservative indication of the health risk posed to the occupants by the VOC associated with the spill. Ventilation of the building should be minimized in the 24 hours prior to and during sampling.

Many variables can influence indoor air sampling including air exchange rates, operation of the building HVAC system, hydrogeologic and meteorological conditions, household activities and chemical usage. All of these variables combine to create site-specific exposure conditions that should be considered in evaluating the indoor air sample results from a home. To account for these variations the following measures should be considered:

- Perform sampling in the lowest level of the structure where vapors are likely to enter, typically the basement or crawl space.
- Perform living area sampling in a room that is used regularly in the lowest level of the structure suitable for occupancy such as a living room, den or playroom.
- Avoid kitchens and laundry rooms where use of personal products and other chemical products may interfere with sample results.
- Close windows and outside doors and keep them closed as much as possible during sampling except for normal entry and exiting.
- Place indoor samplers on stands approximately 1 meter above the floor in a central part of the room away from heaters, heating vents, high humidity, exterior walls, drafts (vents, open doors, and windows, air conditioners, fans) and obstructions to air flow.
- Place the source area sampler near the spill or where vapors may be entering the home (most likely in the basement) approximately 1 meter above the floor.
- All sampling equipment should be placed away from family traffic patterns and out of reach of pets and children.
- Only operate air conditioning units that recirculate interior air.
- Samplers should not be placed close to attached garages, ash trays or other possible VOC sources that might provide results that do not reflect contamination related to the spill/vapor source under investigation.
- Remove or tightly seal obvious indoor sources of petroleum constituents and other VOC sources during indoor air sampling, such as fuels, paints, cleaning solvents and mothballs.
- Document household characteristics, resident activities and potential ambient sources that may influence indoor air sampling results by completing the "Indoor Air Sampling Form".
- Complete a sketch of sampling locations.

The residents of the home should be given the instructions listed below to follow 24 hours prior to and during the sampling event:

- **Do not** open any windows, fireplace openings or vents.
- **Do not** operate ventilation fans unless special arrangements are made.
- **Do not** smoke in the home.
- **Do not** use paints or varnishes.
- **Do not** use wood stove, fireplace or auxiliary heating equipment, e.g., kerosene heaters.
- **Do not** operate or store automobiles in an attached garage.
- **Do not** store containers of gasoline or oil within the house or attached garage (except for fuel oil tanks).
- **Do not** clean or polish furniture or floors with petroleum or oil-based products.
- **Do not** use air fresheners or odor eliminators.
- **Do not** engage in hobbies that use materials containing VOCs.
- **Do not** use cosmetics including hair spray, nail polish, nail polish removers, etc.
- **Do not** apply pesticides.

Quality Control/Quality Assurance

Follow the manufacturer's guidelines for use of sampling equipment and holding times. Field blanks trip blanks and duplicate samples should be kept with and submitted with the samples. Analyze samples as soon as possible after sampling. Record general weather conditions during sampling including ambient temperature. Maintain chain-of-custody forms.

Appendix E
New Hampshire Department of Environmental Services
Waste Management Division
Site Remediation Programs

Derivation of the Indoor Air Screening Levels

This appendix describes the assumptions, toxicity information, equations, indoor air background information and analytical reporting limits used by DES Environmental Health Program (EHP) to develop the indoor air screening levels, provided in Table 1. The approach described in this appendix can also be used to develop indoor air screening guidelines for chemicals not identified in Table 1. In addition, equations are provided in this appendix that can be used to conduct a site-specific risk assessment to determine the potential human health risk to a building occupant based on a site-specific exposure scenario.

The chemicals contained in Table 1 are those identified on DES's Site Remediation Programs Full List of Analytes for Volatile Organics. The list has been limited to those chemicals with inhalation based toxicity factors and a Henry's Law Constant of 1×10^{-5} atm-m^3/mol or greater. EHP developed carcinogenic and non-carcinogenic risk based values for both a residential exposure scenario and a commercial work place exposure scenario using standard exposure factors to estimate contaminant concentrations in indoor air that are considered to be protective of human health. The risk based values were then compared to published background values (residential only) and low level reporting limits for USEPA Method TO-15-LL with the higher value selected as the indoor air screening value.

Dose-Response Information

Dose-response information provides a quantitative evaluation of the toxicity data and allows for characterizing the relationship between the inhaled concentration and the adverse health effect(s) in the exposed population. The scientific literature has been reviewed by various federal agencies and for certain chemicals these agencies have derived and reported dose-response values. Examples of these values include EPA's reference concentrations (RfC) and inhalation Unit Risk (URi).

Estimating the health effects from a mixture of chemicals is of particular concern since most sites contain two or more contaminants present at the same time. When more than a single contaminant is present there is the potential for a diverse array of interactive effects. Such interactions can be in the form of additive, antagonistic, synergistic or other interactive effects. Unfortunately, for most chemical mixtures there is a lack of toxicological data. In addition, when there is data available for mixtures it is difficult to evaluate the effects because of the infinite proportions that could be possible. Therefore, the dose-response values are based on experimental data from exposure to a single chemical and do not consider the effects of exposure to chemical mixtures.

The concentration of a chemical in the air that is inhaled and the amount that reaches the circulatory system and eventually the target organ(s) to elicit the toxic effect is dependent on many variables. These variables include the physiological and metabolic differences in the regions of the respiratory tract, genetic differences between individuals and the health status of the individual. In addition, the physiochemical properties of the inhaled chemical will also influence the systemic or tissue dose and ultimately the toxic effect. Because of the uncertainty involved with determining the tissue dose the

toxicity factors used to develop the risk-based screening guidelines are based on RfCs and URi, which were developed from inhalation studies. If there were no inhalation based toxicity values available from the identified sources EHP chose not to develop a risk-based screening guideline from an extrapolation of an oral toxicity value (cancer slope factor and/or reference doses) to an inhalation value with the exception of trichloroethylene (TCE).

"The RfC methodology used to estimate benchmark values for non-cancer toxicity of inhaled chemicals significantly departed from the RfD approach. The same general principles were used but the RfC methodology was expanded to account for the dynamics of the respiratory system as the portal of entry. The major difference between the two approaches therefore is that the RfC methodology includes dosimetric adjustments to account for the species-specific relationships of exposure concentrations to deposited/delivered doses. The physicochemical characteristics of the inhaled agent are considered key determinants to its interaction with the respiratory tract and ultimate disposition." (USEPA 1994) In summary, a chemical may have a vastly different absorption, distribution, metabolism and portal of entry effect that is not captured by the extrapolation introducing greater uncertainty than values based on inhalation studies.

Toxicity Factors

In 2003, the EPA's Office of Solid Waste and Emergency Response (OSWER) issued Directive 9285.7-53, which provides recommended sources of toxicity data for developing screening levels for various media and conducting site-specific human health risk assessments. The hierarchy of toxicity information recommended by OSWER Directive 9285.7-53 is:

Tier 1– EPA's Integrated Risk Information System (IRIS)

Tier 2 – EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs)

Tier 3 – Other (CAL EPA, ATSDR, HEAST)

The EPA's IRIS database is the generally preferred source of URi and RfCs for evaluating inhalation exposure. The PPRTVs are provisional toxicity values recommended by EPA's National Center for Environmental Assessment (NCEA). PPRTVs are the second recommended tier of toxicity values, however, EPA has restricted access to this database. When IRIS values were not available EHP consulted EPA Region 9's Preliminary Remediation Goals (PRG) table, which contains the latest recommended toxicity factors according to the OSWER directive. Please note that the toxicity values identified on IRIS are frequently updated. It is incumbent upon the users of this guidance to check IRIS and EPA Region 9's PRG Table to verify that the most current toxicity information is being when completing site-specific human health risk assessments.

Carcinogenic Effects

For carcinogenic chemicals an assumption is made that there are no thresholds and that exposure introduces some potential of developing cancer. The risk based values for carcinogenic chemicals are based on an excess lifetime cancer risk (ELCR) of one-in-one million (1.0E-6) exposed for a residential scenario that assumes an individual is exposed 22 hours per day, 350 days per year for a duration lasting 30 years. The risk based values for a commercial worker assumes exposure for 8 hours per day, 5 days per week for 50 weeks per year (250 days per year total) for a duration lasting 25 years.

EHP has elected to calculate the carcinogenic risk-based screening values using the URi. The URi defines quantitatively the relationship between the dose and the response and is defined as the upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 $\mu g/m^3$ in air.

Non-carcinogenic Effects

For non-carcinogens a range of exposures are believed to exist that can be tolerated with little likelihood of expression of an adverse health effect. The dose-response value derived by the EPA to protect against non-carcinogenic threshold effects is the reference concentration (RfC). The RfC 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 appreciable risk of deleterious non-cancer health effects during a lifetime." (USEPA IRIS)

For this guidance, EHP has selected 20 percent of the chronic non-cancer dose-response value as the risk-based non-cancer value for a residential scenario. For a commercial scenario, EHP used 20 percent of the adjusted RfC. The RfC was adjusted to account for the assumed exposure of 5 days per week for 50 weeks per year (250 days per year total) over a duration lasting 25 years. By using 20 percent of the adjusted RfC, the commercial risk based value is still below the full RfC and therefore portal of entry effects should not be a concern.

Screening Level Equations

Carcinogens:

Equation #1 C_{cancer} ($\mu g/m^3$) = (TCR * AP * HD) / (EF * ED* URi * ET)

Non-carcinogens:

Equation #2 $C_{non\text{-}cancer}$ ($\mu g/m^3$) = (HQ * RfC)

Where:

C_{cancer}	= target indoor air concentration for a carcinogen ($\mu g/m^3$)
TCR	= target cancer risk (1.0E-6)
AP	= averaging period carcinogens (25550 days)
HD	= hours in a day (hours/day)
EF	= exposure frequency (days/year)
ED	= exposure duration (years)
URi	= unit risk factor inhalation ($\mu g/m^3$)
ET	= exposure time (hours/day)

$C_{non\text{-}cancer}$	= target indoor air concentration for a non-carcinogen ($\mu g/m^3$)
HQ	= target hazard quotient (0.2)
RfC	= reference concentration ($\mu g/m^3$)

The carcinogenic and non-carcinogenic risk based values, for residential and commercial exposure scenarios are provided in Table E-1.

Indoor Air Background Values

In order to take into account background levels of chemicals, DES reviewed two indoor air studies listed below.

- "Study of Volatile Organic Chemicals in Air of Fuel Oil Heated Homes." New York State Department of Health, 1997-2003.
- "Background Indoor Air Levels of Volatile Organic Compounds (VOCs) and Air-Phase Petroleum Hydrocarbons in Massachusetts Residences," completed by Rich Rago and Rose McCafferty, Haley & Aldrich, and Andy Rezendes, Alpha Analytical, presented to NHDES October 2005.

Where a chemical was detected in at least 25% of homes sampled in the studies noted above, the 75th percentile values for each study were compared and the lower value was selected to represent a residential background value for indoor air. The indoor air background values used in the derivation of the residential indoor air screening levels are presented in Table E-2.

Selection of the Indoor Air Screening Levels

For the indoor air screening levels, DES took into account risk based values, method reporting limit and indoor air background values (residential only). For the development of the residential indoor air screening levels, DES compared the most conservative (lowest) risk based value, the EPA Method TO-15-LL reporting limit and a residential indoor air background value, where available. The higher of these values was selected to represent the residential indoor air screening levels provided in Table 1 of the guidance. For the development of the commercial indoor air screening levels DES selected the most conservative (lowest) risk based value compared to the EPA Method TO-15-LL reporting limit and selected the higher of the two values as the commercial indoor air screening levels provided in Table 1 of the guidance. The risk based values for residential and commercial exposures, EPA Method TO-15-LL reporting limit and the residential background values used to generate the indoor air screening levels are detailed in Table E-2.

Site-Specific Risk Assessments

The risk-based indoor air values are based on conservative scenarios. A site-specific risk assessment can be conducted when an indoor air screening guideline is exceeded or when the exposure scenario is different from the scenario used to develop the risk-based screening guidelines. The object of the site-specific risk assessment is to evaluate the reasonable maximum exposed (RME) individual at the site which is the highest possible exposure that is reasonably expected to occur. The RME should be used for both the current and future uses of the building. To account for the different exposure scenarios possible the following formulas can be used to determine the potential risk at a site. Please note that these equations are to evaluate the inhalation pathway. If other media are impacted the risk from all other potential pathways should be included in a Method 3 risk characterization. Guidelines for conducting a Method 3 risk characterization are outlined in the DES Contaminated Sites Risk Characterization and Management Policy.

Equation #3 $ADE = C * ET * EF * ED * C1 * C2 / AP$

Carcinogenic risk:

Equation #4 Risk = ADE * URi

Non-carcinogenic risk:

Equation #5 HQ = ADE / (RfC)

Where:

ADE = average daily exposure ($\mu g/m^3$)
URi = inhalation unit risk $(\mu g/m^3)^{-1}$
C = concentration chemical specific ($\mu g/m^3$)
ET = exposure time (hours/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
C1 = conversion factor (day/hour) (0.042)
C2 = conversion factor (year/day) (0.003)
AP = averaging period (years)
carcinogens = 70 years
non-carcinogens = site-specific (ED)
HQ = hazard quotient (chemical specific)
RfC = reference concentration chemical specific ($\mu g/m^3$)

For multiple carcinogenic chemicals at a site the site-specific cancer risk should be totaled.

$Risk_T$ = Sum $Risk_i$ (expressed to one significant figure)
Where:

$Risk_T$ = the total cancer risk expressed as a unitless probability
$Risk_i$ = the risk estimate for the ith substance

If $Risk_T$ is greater than 1.0E-5, the DES considers the risk from the inhalation pathway to be significant.

When more than one non-carcinogenic substance is at the site the quantification of the non-cancer hazard can be determined by:

Hazard Index (HI) = Sum HQ_i

Where:

HQ = hazard quotient (ADE_i/RfC_i)
ADE = the intake for the ith toxicant
RfC = reference concentration for the ith toxicant

The ADE and RfC are expressed in the same units and represent the same exposure periods. If the HI is greater than unity (1.0) as a consequence of summing several hazard quotients of similar value it

would be appropriate to segregate the compounds by effect on target organ and to derive a separate hazard indice for each target organ. Table E-1 contains the RfCs for chemicals listed in this guidance document. For chemicals not contained in this document the user should consult IRIS or EPA Region 9's RBC table.

For some chemicals there are both carcinogenic and non-carcinogenic toxicity factors available. For the development of screening guidelines EHP has calculated separate screening values using both types of toxicity values if available and selected the most conservative (lowest) to represent the risk-based screening guideline. The risk-based guideline is then compared to the reporting limit of EPA Method TO-15-LL. Please note that it is incumbent upon the risk assessor to account for both potential carcinogenic and non-carcinogenic end points in a site-specific risk assessment if appropriate.

Exposure Variables

The exposure variables EHP typically recommends for the residential and occupational scenarios are identified below. Exposure parameters that are adjusted based on a site-specific basis should be protective of current and future use scenarios. When exposure parameters are different from those recommended in this guidance, DES encourages the use of EPA's Exposure Factors Handbook. If an exposure is expected to be less than seven years consideration should be given to using sub chronic RfCs from a published source. If a sub chronic RfC is not available, the chronic RfC should be used unless justification is provided for altering the chronic RfC.

Residential:

EF	= exposure frequency	=	350 days/year
ED	= exposure duration total		= 30 years
	= exposure duration average	=	9 years[13]
ET	= exposure time		= 22 hours/day

Occupational:

EF	= exposure frequency	=	250 days/year
ED	= exposure duration	=	25 years
ET	= exposure time		= 8 hours/day

TABLE E-1

Chemical	CAS No.	URi (µg/m³)	Residential 1.0E-6 ELCR (µg/m³)	Commercial 1.0E-6 ELCR (µg/m³)	Source	RfC (µg/m³)	Residential 20 % RfC (µg/m³)	Commercial 20 % RfC (µg/m³)	Source
Benzene	71-43-2	7.80E-06	0.34	1.57	IRIS	30	6.00	8.76	IRIS
Bromoform	75-25-2	1.10E-06	2.41	11.15	IRIS				
Bromomethane	74-83-9					5	1.00	1.46	IRIS
Carbon tetrachloride	56-23-5	1.50E-05	0.18	0.82	IRIS				
Chlorobenzene	108-90-7					60	12.00	17.52	PPRTV
12-Dichlorobenzene	95-50-1					200	40.00	58.40	HEAST
14-Dichlorobenzene	106-46-7					800	160.00	233.60	IRIS
11-Dichloroethane	75-34-3					500	100.00	146.00	HEAST
12-Dichloroethane	107-06-2	2.60E-05	0.10	0.47	IRIS				
11-Dichloroethylene	75-35-4					200	40.00	58.40	IRIS
Dichloromethane (Methylene chloride)	75-09-2	4.70E-07	5.65	26.09	IRIS	3000	600.00	876.00	HEAST
12-Dichloropropane	78-87-5					4	0.80	1.17	IRIS
Ethylbenzene	100-41-4					1000	200.00	292.00	IRIS
Ethylene dibromide	106-93-4	6.00E-04	0.004424	0.020440	IRIS	9	1.80	2.63	IRIS
Methyl ethyl ketone	78-93-3					5000	1000.00	1460.00	IRIS
Methyl isobutyl ketone	108-10-1					3000	600.00	876.00	IRIS
Methyl-t-butyl ether (MTBE)	1634-04-4	8.00E-7	3.3	15.3		3000	600.00	876.00	IRIS
Styrene	100-42-5					1000	200.00	292.00	IRIS
1122-Tetrachloroethane	79-34-5	5.80E-05	0.05	0.21	IRIS				
Tetrachloroethylene	127-18-4	5.90E-06	0.45	2.08	Cal EPA	35	7.00	10.22	Cal EPA
Toluene	108-88-3					5000	1000.00	1460.00	IRIS
124-Trichlorobenzene	120-82-1					3.5	0.70	1.02	PPRTV
111-Trichloroethane	71-55-6					2200	440.00	642.40	PPRTV
112-Trichloroethane	79-00-5	1.60E-05	0.17	0.77	IRIS				
Trichloroethene	79-01-6	1.10E-04	0.02	0.11		40	11.68		NCEA
Trichloromethane (Chloroform)	67-66-3	2.30E-05	0.12	0.53	IRIS				
124-Trimethylbenzene	95-63-6					6	1.20	1.75	PPRTV
135-Trimethylbenzene	108-67-8			2.79		6	1.20	1.75	PPRTV
Vinyl chloride	75-01-4	8.80E-06	0.30		IRIS	100	20.00	29.20	IRIS
Total Xylenes	1330-20-7					100	20.00	29.20	IRIS
Naphthalene	91-20-3					3	0.60	0.88	IRIS

TABLE E-2

Chemical	CAS No.	Groundwater Screening Value GW-2 (µg/L)	Residential Soil Gas Screening Value (µg/m3)	Commercial Soil Gas Screening Value (µg/m3)	Residential Indoor Air Screening Value (µg/m^3)	Commercial Indoor Air Screening Value (µg/m^3)	Residential Indoor Air Background Value (µg/m^3)	Residential Indoor Air Risk Based Value (µg/m^3)	Commercial Indoor Air Risk Based Value (µg/m^3)	Method Reporting Limit TO-15 LL (µg/m^3)
Benzene	71-43-2	2,000	95	95	1.9	1.9*	1.9	0.34	1.57	0.64
Bromoform	75-25-2	2,000	120	550	2.4	11	NA	2.41	11.15	2.07
Bromomethane	74-83-9	10	50	73	1.0	1.5	NA	1.00	1.46	0.78
Carbon Tetrachloride	56-23-5	40	63	63	1.3	1.3	0.59	0.18	0.82	1.26
Chlorobenzene	108-90-7	3,000	600	880	12	18	NA	12	17.52	0.92
Chloroform	67-66-3	200	49	49	1.0	1.0	0.54	0.12	0.53	0.98
Dichlorobenzene 12-	95-50-1	20,000	2000	2900	40	58	NA	40	58	1.20
Dichlorobenzene 14-	106-46-7	50,000	8000	12000	160	230	0.54	160	234	1.20
Dichloroethane 11-	75-34-3	10,000	5000	7300	100	150	NA	100	146	0.81
Dichloroethane 12-	107-06-2	300	40	40	0.8	0.8	NA	0.10	0.47	0.81
Dichloroethylene 11-	75-35-4	1,000	2000	2900	40.0	58	NA	40	58	0.79
Dichloromethane (Methylene Chloride)	75-09-2	1,000	280	1300	5.6	26	4.2	5.65	26	1.74
Dichloropropane 12-	78-87-5	200	46	59	0.9	1.2	NA	0.80	1.17	0.92
Ethylbenzene	100-41-4	50,000	10000	15000	200	290	2.2	200	292	0.87
Ethylene dibromide	106-93-4	700	77	77	1.5	1.5	NA	0.004	0.02	1.54
Methyl ethyl ketone	78-93-3	50,000	50000	73000	1000	1500	7.3	1000	1460	1.47
Methyl isobutyl ketone	108-10-1	50,000	30000	44000	600	880	0.86	600	876	2.05
Methyl tert butyl ether	1634-04-4	10,000	280	770	5.6	15	5.6	3.3	15	1.80
Naphthalene	91-20-3	2,000	130	130	2.6	2.6	NA	0.60	0.88	2.62
Styrene	100-42-5	50,000	10000	15000	200	290	0.64	200	292	0.85
Tetrachloroethane 1122-	79-34-5	1,000	69	69	1.4	1.4	NA	0.05	0.21	1.37
Tetrachloroethylene (PCE)	127-18-4	80	68	100	1.4	2.1	1.1	0.45	2.08	1.36
Toluene	108-88-3	50,000	50000	73000	1000	1500	18	1000	1460	0.75
Trichlorobenzene 124-	120-82-1	1,000	190	190	3.7	3.7	NA	0.70	1.02	3.71
Trichloroethane 111-	71-55-6	20,000	22000	32000	440	640	1.1	440	642	1.09
Trichloroethane 112-	79-00-5	500	55	55	1.1	1.1	NA	0.17	0.77	1.09
Trichloroethylene (TCE)	79-01-6	50	54	54	1.1	1.1	NA	0.02	0.11	1.07
Trimethylbenzene 124	95-63-6	3,000	220	220	4.3	4.3*	4.3	1.20	1.75	0.98
Trimethylbenzene 135	108-67-8	1,000	85	88	1.7	1.8	1.7	1.20	1.75	0.98
Vinyl chloride	75-01-4	10	26	140	0.5	2.8	NA	0.30	2.79	0.51
Xylenes (mixed isomers)	1330-20-7	30,000	1000	1500	20.0	29	7.7	20	29	0.87

Appendix E References

US EPA. October 1994. Methods for Derivation of Inhalation Reference Concentrations and Application of Inhalation Dosimetry. EPA/600/8-90/066F.

US EPA 2001.Trichloroethylene Health Risk Assessment: Synthesis and Characterization (External Review Draft). EPA/600/P-01/002A
http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=23249

US EPA. Integrated Risk Information System (IRIS).
http://www.epa.gov/iriswebp/iris/index.html

Provisional Peer Reviewed Toxicity Values for Superfund (PPRTV). http://hhpprtv.ornl.gov/

US EPA. October 2004. Region 9 Preliminary Remediation Goals.
http://www.epa.gov/region09/waste/sfund/prg/index.htm

US EPA. August 1997. Exposure Factors Handbook. Office of Research and Development. EPA/600/P-95/002Fa.