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

6.4.3 Sub-slab Soil Gas Sampling

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

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

- There are fewer surrounding buildings that are being sampled (that could have helped the understanding of typical sub-slab values and variability).[65]
- The indoor and sub-slab concentrations for a specific building(s) are out of line with expectations based on data from neighboring homes and other information.

---

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

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

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

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

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

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

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

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

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

---

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

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

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

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

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

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

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

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

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

6.4.4 Soil Gas Sampling

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

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

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

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

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

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

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

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

6.4.5 Groundwater Sampling

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

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

6.4.6 Planning for Building and Property Access

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

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

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

---

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

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

6.5 Overview of Risk-Based Screening

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

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

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

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

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

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

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

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

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

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

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

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

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

- A source of vapors underneath the building(s) either in the vadose zone or in the uppermost, continuous zone of groundwater.

- Vapor migration via diffusion upwards through unsaturated soils from these sources toward the ground surface and overlying buildings.

- Buildings with poured concrete foundations (e.g., basement or slab-on-grade foundations) that are susceptible to soil gas entry.

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

- Significant openings to the subsurface that facilitate soil gas entry into the building (e.g., sumps, unlined crawl spaces, earthen floors) other than typical utility penetrations.

- Very shallow groundwater sources (e.g., depths to water less than five feet below foundation level) (see, for example, EPA (2012a), Section 5.2).

- Significant preferential pathways for subsurface vapor migration whether naturally-occurring (e.g., fractured bedrock) or anthropogenic.

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

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

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

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

- Leaking vapors from gas transmission lines.

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

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

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

6.5.2 Recommended Attenuation Factors for Health-based Screening

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

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

---

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

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

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

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

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

---

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

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

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

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

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

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

6.5.3 Comparing Sample Concentrations to Health-based Screening Levels

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

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

---

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

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

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

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

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

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

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

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

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

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

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

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

6.5.4 Planning for Communication of Sampling Results

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

6.6 General Principles and Recommendations for Modeling

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

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

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

Three approaches exist for applying mathematical models in these circumstances:

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

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

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

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

Three examples follow where differing model applications would be useful:

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

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

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

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

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

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

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

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

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

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

7.0 RISK ASSESSMENT AND MANAGEMENT FRAMEWORK

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

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

- Whether to install engineered exposure controls to prevent or reduce the impacts of vapor intrusion in specific buildings.
- Whether to remediate subsurface vapor sources for the site to reduce risks posed by vapor intrusion.
- Whether the vapor intrusion pathway is incomplete and there is no potential for human exposure under current or future conditions.
- Whether to collect additional information as part of the detailed vapor intrusion investigation or monitor indoor air as part of an overall vapor intrusion remedy.

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

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

7.1 Collect and Weigh Site-specific Lines of Evidence

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

<u>Subsurface Vapor Sources</u>

- Site history and source of the contaminants to demonstrate that vapor-forming chemicals have been or may have been released to the underlying and surrounding subsurface environment and identify the type of vapor source (e.g., vapor-forming chemicals dissolved in groundwater or present in a NAPL).
- Groundwater data (generally recommended from more than one sampling event), as appropriate, to confirm the presence of a water-table aquifer as a source of vapors, if applicable, and establish its chemical and hydrogeologic characteristics.

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

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

<u>Vapor Migration and Attenuation in the Vadose Zone</u>

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

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

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

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

<u>Building Foundation Assessment, Including Susceptibility to Soil Gas Entry</u>

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

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

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

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

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

Interior Assessment

- Sub-slab (or crawl space) soil gas data (generally recommended from more than one sampling event and in multiple locations) to assess concentrations potentially available for entry with any intruding soil gas.
- Indoor air sampling data (generally recommended from more than one sampling event[75] and for multiple locations in a given building) to assess the presence of subsurface contaminants in indoor air, estimate potential exposure levels to building occupants to support site-specific exposure and risk assessments (see Section 6.7.2), and otherwise diagnose vapor intrusion.
- Results of mathematical modeling that rely upon site-specific inputs.
- Comparative evaluations of indoor air and sub-slab soil gas data, including calculation and comparison of building-specific, empirical attenuation factors (EPA 2012a, Section 3.0) (e.g., to assess their consistency among subsurface contaminants to assist in identifying indoor vapors arising from vapor intrusion).

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

- Building-specific indoor sources of volatile chemicals.
- Concurrent outdoor air data to assess potential contributions of ambient air to indoor air concentrations.

Additional Supporting Lines

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

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

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

---

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

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

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

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

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

7.2 Assess Concordance Among the Lines of Evidence

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

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

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

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

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

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

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

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

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

7.3 Evaluate Whether the Vapor Intrusion Pathway is Complete or Incomplete

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

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

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

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

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

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

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

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

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

7.4 Conduct and Interpret Human Health Risk Assessment

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

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

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

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

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

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

7.5 Concentration Levels Indicating Potential Need for Prompt Response Action

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

---

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

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

7.5.1 Potential Explosion Hazards

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

7.5.2 Considering Short-term and Acute Exposures

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

7.6 Potential Response Actions

Response actions that may be implemented in existing buildings include:

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

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

---

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

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

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

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

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

8.0 BUILDING MITIGATION AND SUBSURFACE REMEDIATION

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

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

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

8.1 Subsurface Remediation for Vapor Source Control

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

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

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

8.2 Building Mitigation for Vapor Intrusion

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

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

8.2.1 Temporary Measures for Existing Buildings

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

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

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

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

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

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

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

8.2.2 Engineering Controls for Existing Buildings

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

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

---

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

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

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

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

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

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

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

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

---

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

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

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

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

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

TABLE 8 1
VAPOR INTRUSION MITIGATION QUICK GUIDE FOR EXISTING BUILDINGS

Step 1: Consider Temporary Measures

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

8.2.3 Approaches and Considerations for New Buildings

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

- At some sites, contaminated areas most likely to produce unacceptable vapor intrusion exposures can be avoided and designated for another purpose, such as recreational space or undeveloped landscape.

- Mitigation needs can also be considered in the selection of heating and cooling systems, which are normally selected based only on economics, aesthetics, preference, and custom. A system design that avoids creating under-pressurization inside the structure and maintains over-pressurization inside the structure may be effective in mitigating vapor intrusion.

- Passive barriers, such as a low-permeability membrane, can be more readily installed between the soil and the building during new building construction. Passive barriers are intended to reduce vapor intrusion by limiting entry routes. Passive barriers as stand-alone technologies may not adequately reduce vapor intrusion owing to difficulties in their installation and the potential for perforations of the barrier during or after installation. They are commonly combined with ADT systems or with sub-membrane ventilation systems to help improve their efficiency.

- Venting layers can be more readily installed between the soil and the building during new building construction.[85]

- Sometimes, new buildings can be designed to include a highly ventilated, low-occupancy area at ground level, such as an open parking garage.

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

---

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

8.2.4 Owner/Occupant Preferences and Building Access

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

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

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

8.3 Operation and Maintenance of Vapor Intrusion Mitigation Systems

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

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

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

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

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

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

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

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

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

    - Confirmation that the extraction fan is operating.

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

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

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

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

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

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

8.4 Monitoring of Vapor Intrusion Mitigation Systems

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

Pressure Measurements

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

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

Air Sampling

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

Weather-Related Considerations

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

Alarms

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

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

8.5 Documentation of Vapor Intrusion Mitigation Systems

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

O&M Plan

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

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

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

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

---

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

O&M Manual

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

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

User's Guide

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

8.6 Use of Institutional Controls

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

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

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

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

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

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

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

8.6.1 Evaluating ICs in the Overall Context of Response Selection

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

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

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

8.6.2 Common Considerations and Scenarios Involving ICs

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

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

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

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

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

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

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

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

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

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

IC EXAMPLE 1:

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

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

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

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

IC EXAMPLE 2: State IC Legislation

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

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

8.6.3 Selecting the Right Instrument(s)

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

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

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

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

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

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

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

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

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

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

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

---

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

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

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

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

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

8.6.4 Long-term Stewardship

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

Periodic Reviews

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

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

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

---

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

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

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

[97] See CERCLA section 121(c).

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

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

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

IC Planning Documents

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

8.6.5 Community Involvement and ICs

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

8.7 Termination/Exit Strategy

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

---

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

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

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

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

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

8.7.1 Termination of Subsurface Remediation Activities

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

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

8.7.2 Termination of Building Mitigation

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

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

Active Building Mitigation

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

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

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

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

Passive Building Mitigation

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

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

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

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

8.7.3 Termination of Requirement for ICs

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

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

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

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

8.7.4 Termination of Monitoring

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

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

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

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

9.0 PRE-EMPTIVE MITIGATION/EARLY ACTION

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

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

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

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

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

9.1 Rationale

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

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

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

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

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

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

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

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

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

9.2 Statutory/Regulatory Basis for Taking Action with Limited Data

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

9.2.1 CERCLA and the NCP

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

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

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

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

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

9.2.2 RCRA Corrective Action

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

9.3 General Decision Framework

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

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

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

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

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

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

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

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

9.4 Some General Scenarios Where Preemptive Mitigation May be Warranted

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

9.4.1 Site with Single Building and Limited Data

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

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

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

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

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

9.4.2 Site with Multiple Buildings and Limited Data

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

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

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

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

9.4.4 Future Construction and Development

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

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

9.5 Additional Considerations

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

9.5.1 Weighing of Relative Costs of Characterization versus Engineered Exposure Controls

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

---

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

9.5.2 Institutional Controls

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

9.5.3 Community Input and Preferences

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

Others may be reluctant to install mitigation systems because of the operation costs or the inconvenience associated with the installation and subsequent monitoring. Although some owners may view mitigation systems as an advantage when they sell a property, others may be concerned with the possible negative effect on property values.

Issues and concerns about equity and fairness can also arise when some homes within a neighborhood receive mitigation systems and others do not. In some situations, it may be easier to persuade property owners to install vapor intrusion mitigation systems if the entire street, block, or neighborhood is found to warrant early action.

Public meetings and one-on-one meetings provide opportunities to discuss PEM with affected property owners and building occupants and obtain information and input. Section 10.0 of this document provides additional information and guidance about community involvement and engagement.

Figure 9-1a: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Single Building (Rural Setting)

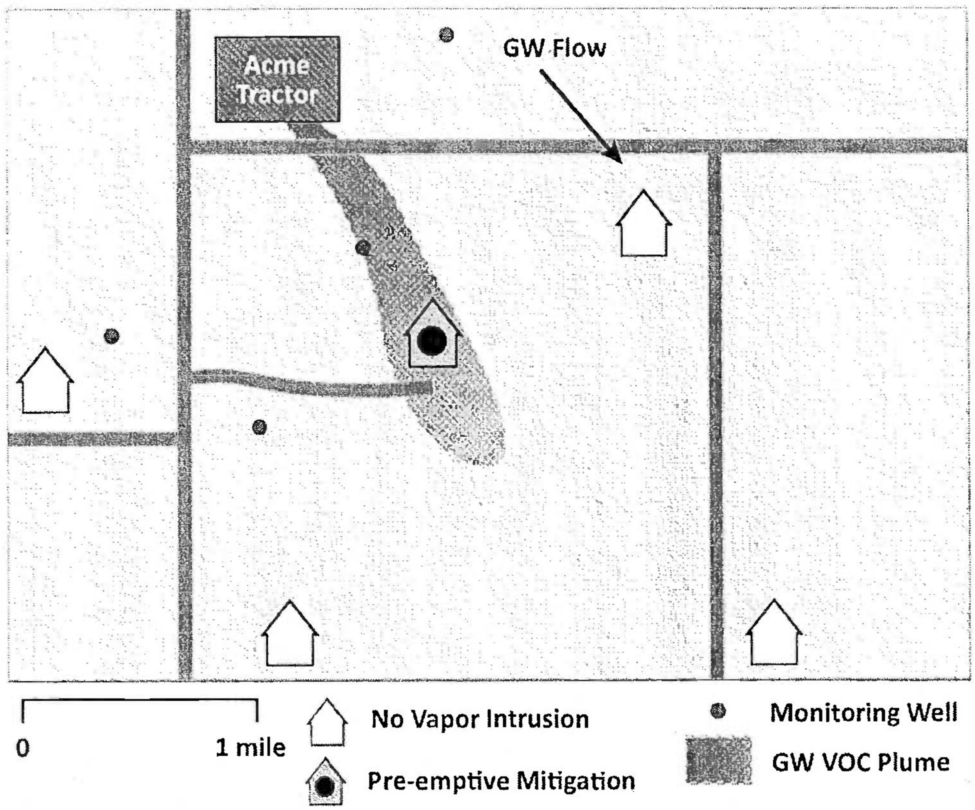


Figure 9-1b: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Single Building (Suburban Setting)

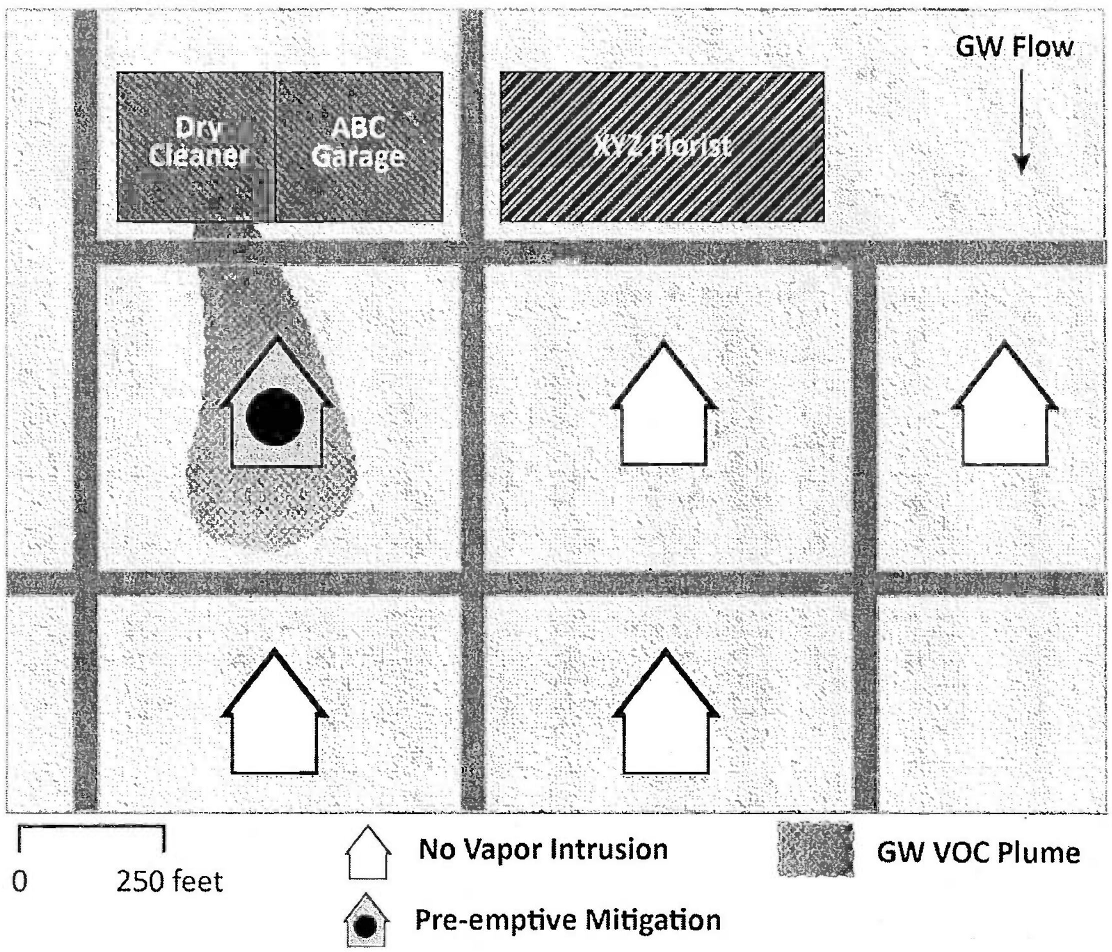


Figure 9-2: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Multiple Buildings, Each with Limited Data

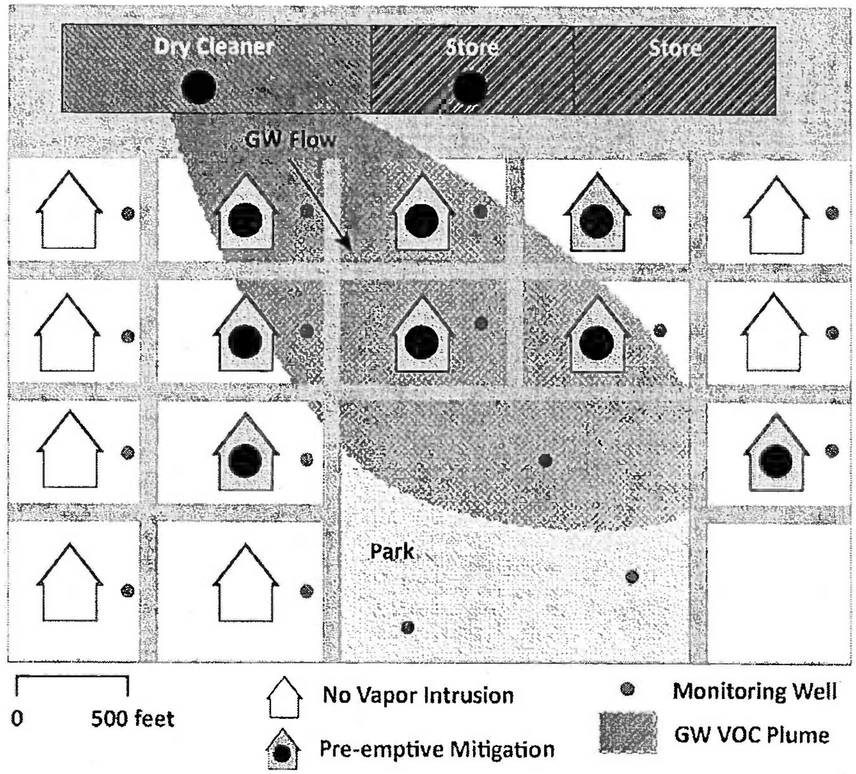
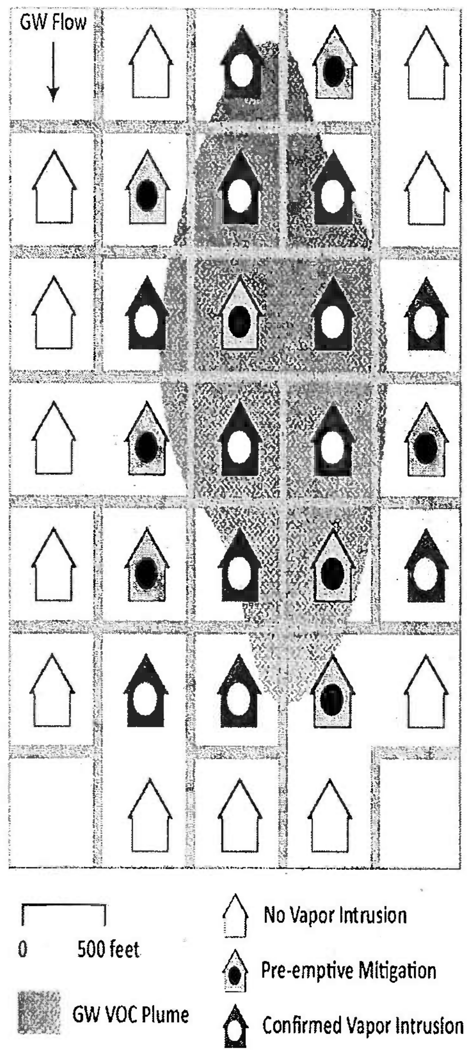


Figure 9-3: Sample Depiction of Subsurface Vapor Source and Data to Support Preemptive Mitigation/Early Action for Multiple Buildings, Some with Only Limited or No Data



10.0 PLANNING FOR COMMUNITY INVOLVEMENT

Communicating information about environmental risk is one of the most important responsibilities of risk managers and community decision-makers. Simply stated, risk communication, whether written, verbal, or visual statements concerning risk, is the process of informing people about potential and perceived hazards to their person, property, or community. In discussing risk, it should be put into context. Recognize that there are personal, cultural and societal dimensions of risk. Include advice about risk-reduction behavior and encourage a dialogue between the sender and receiver of the message. The best risk communication occurs in contexts in which the participants are informed about risks they are concerned about, the process is fair, and the participants are free and able to solve whatever communication difficulties arise. *Risk Communication in Action: The Risk Communication Workgroup* (EPA 2007) is one of several resources available that explain the elements of successful risk communication and describe communication tools and techniques.

Thus, community involvement is a key component of any site investigation or other EPA response action. Members of the public affected by environmental contamination should be aware of what EPA is doing in their community and have a say in the decision-making process. Stakeholder and community involvement is particularly important for sites with vapor intrusion issues, in part because the exposure to toxic vapors may pose a significant risk that is unknown to inhabitants (in the absence of mitigation systems), as they potentially arise in homes, workplaces, schools, and places of commerce and gathering. Stakeholder and community involvement should be conducted from the earliest stage of the site assessment and risk assessment process, with on-going education, two-way communication, and discussion throughout the entire process to create community trust and acceptance.

Community involvement activities should be initiated as soon as possible after determining that vapor intrusion may exist at a particular site. Informing the community about vapor intrusion concerns and plans to conduct an assessment, including sampling, can be resource intensive. Because of the intrusive nature of assessment and mitigation, stakeholder involvement is important throughout the process.

Public Participation and Risk Communication

A meaningful community involvement process requires knowledge of effective public participation and risk communication practices. Public participation refers to the full range of activities that EPA uses to engage communities in the Agency's decision-making process. In 2003, EPA updated its Public Involvement Policy.[102] Its foundation includes seven basic steps to support effective public participation:

1) Plan and budget.

2) Identify those to involve.

3) Consider providing assistance.

[102] EPA Public Involvement Policy (2003): http://www.epa.gov/publicinvolvement/policy2003/index.htm.

4) Provide information.

5) Conduct involvement.

6) Review and use input and provide feedback to the public.

7) Evaluate involvement.

To help implement the steps, EPA developed a series of brochures[103] on effective public participation that outline how to budget for, plan, conduct, and evaluate public participation.

EPA Program-Specific Community Involvement Guidance and Recommendations

CERCLA and other EPA regulations[104] require specific community involvement activities that must occur at certain points throughout the cleanup process. Specifically, in 2005, OSWER published the *Community Involvement Handbook*[105] (EPA 540-K-05-003). The handbook presents legal and policy requirements for Superfund community involvement and includes additional suggestions for involving the community in the Superfund process. In addition, EPA's *Proposed Guidelines for Brownfields Grants* require applicants to describe their plans for involving community-based organizations in site cleanup and reuse decisions.[106] The *Grant Funding Guidelines for State and Tribal Response Programs* for brownfields funding also require programs to establish, at a minimum, "mechanisms and resources to provide meaningful opportunities for public participation."[107] In addition, in 1995, EPA promulgated the *RCRA Expanded Public Participation* rule (60 FR 63417-34, December 11, 1995)[108] which created additional opportunities for public involvement in the permitting process and increased access to permitting information.[109]

At sites with vapor intrusion issues, EPA recommends that the site planning team (i.e., the remedial project manager (RPM) or on-scene coordinator (OSC); community involvement coordinator (CIC); risk assessor; the enforcement case team; EPA contractor; state, tribal, or local agency staff; or others) to consider the following:

- Develop a community involvement plan (CIP) or update the existing CIP.

---

[103] http://www.epa.gov/publicinvolvement/brochures/index.htm

[104] 40 CFR §300.155 http://edocket.access.gpo.gov/cfr_2003/julqtr/pdf/40cfr300.155.pdf

[105] EPA *Superfund Community Involvement Handbook*: http://www.epa.gov/superfund/community/cag/pdfs/ci_handbook.pdf

[106] EPA Brownfields Grants website: http://www.epa.gov/brownfields/cleanup_grants.htm

[107] EPA Brownfields State and Tribal Response Program Grants website: http://www.epa.gov/brownfields/state_tribal/fund_guide.htm

[108] Section 7004(b) of the Resource Conservation and Recovery Act provides EPA broad authority to encourage and assist public participation in the development, revision, implementation, and enforcement of any regulation, guideline, or program under RCRA.

[109] EPA *RCRA Public Participation Manual*: http://www.epa.gov/osw/hazard/tsd/permit/pubpart/manual.htm

- Learn about the site and the community to foster development of a CIP that highlights key community needs, concerns and expectations.

- Commit to ongoing, sustained communication activities throughout vapor mitigation and site cleanup efforts.

- Develop a communication strategy[110] and conduct outreach to inform stakeholders about the facts and findings pertaining to the site.

- Obtain written permission, if appropriate and necessary, for building/property access, and involve the property owner/occupant in identifying or removing potential indoor air contamination sources, including inspection of residence and completing an occupant survey.

- Fully communicate and interpret sampling results, and evaluate mitigation options, if applicable.

When considering the most effective community involvement strategies, EPA recommends that its previous involvement be considered, as well as the existence of community or neighborhood groups and the phase of the regulatory process in which vapor intrusion is being addressed. Additional resources for planning and implementing effective community involvement activities are discussed in Section 10.2: Communication Strategies and Conducting Community Outreach.

10.1 Developing a Community Involvement or Public Participation Plan

A CIP is a site-specific strategy to enable meaningful community involvement throughout the cleanup process.[111] CIPs specify EPA-planned community involvement to address community needs, concerns, and expectations that are identified through community interviews and other means. A CIP will enable community members to understand the ways in which they can participate in decision-making throughout the cleanup process. The purpose of the CIP is not to provide technical answers to the community's questions. Rather, the CIP is EPA's plan for informing and involving the community in the cleanup process and can be a powerful way to communicate EPA's commitment to listening and responding to community concerns, and provide timely information and opportunities for community involvement.

The CIP should be a "living" document and is most effective when it is updated or revised as site conditions change. When developing the CIP document, EPA recommends that the site planning team should consider following steps:

---

[110] A communication strategy can be one component of a CIP, but it addresses a specific event, issue, or concern, such as an emergency response to a release, or communicating risk at a site. The CIP, on the other hand, describes an overall strategy for conveying information throughout the cleanup process at a site.

[111] *EPA Superfund Community Involvement Toolkit.* 2011. *Community Involvement Plans.* Available at: http://www.epa.gov/superfund/community/pdfs/toolkit/ciplans.pdf

Describe the Environmental Setting and Cleanup Process

Describe the release and affected areas (the site). This includes information about the site, its history, the key issues related to site contamination, and how vapor intrusion fits into EPA's overall cleanup effort at the site.

Describe and Learn about the Community

Describe the community. The community profile is a description of the affected community that summarizes demographic information and identifies significant subgroups in the population, languages spoken, and other important characteristics of the affected community, such as whether the site is located in an area with environmental justice concerns or includes sensitive populations. It also should include information about how the profile was derived.

Learn about community needs, concerns and expectations: Issues of concern to residents and business owners are identified through community interviews, informal discussions and interactions, local media reports, and other insights about the affected community. Questions may include:

- What are public perceptions and opinions of EPA and the cleanup process?
- How do people want to be kept informed (i.e., mechanisms to deliver information)?
- How do people want to be included in the decision-making process?
- What are the perceived barriers to effective public participation?
- Are there other sources of pollution that affect the community?
- Have there been past experiences of mistrust or any unique concerns?

This information can be used to recommend any special services to be provided, including technical assistance, formation of a Community Advisory Group, facilitation/conflict resolution, or translation services.

Write and Compile the CIP

Once the site planning team has learned about the community, it is time to put the information together in a way that will be useful to EPA and the community. In addition to the site description, community description, and community needs and concerns, the CIP also may include a reference listing of contacts (name, address, phone, email) useful for the community or the site planning team. Consider whether permission should be obtained before including contact information for some of the people listed. EPA recommends that the contact list include contact information for:

- The site planning team.

- Community groups and community leaders.
- Local elected officials.
- Local, state, tribal, and federal agency staff relevant to the site.
- Media contacts (including social media outlets and community journalists).
- Others, as appropriate.

To ensure that the CIP is indeed informed by the community, EPA recommends that a draft of the CIP be shared with the community, and their input and feedback be invited along the way. The CIP should offer a clear invitation to the community for feedback before it is finalized. Again, the CIP should be a "living" document and is most effective when it is updated or revised as site conditions change. In some cases, particularly when the CIP is updated or revised for a FYR or where community interest is minimal, a short CIP outlining EPA's plan for community involvement may be all that is needed. For most sites, EPA recommends that the CIP be written to address the community directly, and their active involvement be invited at each stage of the cleanup process.

10.2 Communication Strategies and Conducting Community Outreach

EPA recommends that community outreach activities be initiated as soon as possible after determining that vapor intrusion may exist at a particular site. Informing and educating the community includes distributing information and providing opportunities for EPA to listen to community concerns. Community outreach activities should be tailored to the community based on information gleaned from community interviews and other methods used in developing the CIP. Public health officials from state or local agencies may be helpful in communicating risk information and answering questions from the community.

<u>Communication Strategies</u>

Communication strategies are plans for communicating information related to a specific issue, event, situation, or audience. They serve as the blueprints for communicating with the public, stakeholders, or even colleagues, and should specify the mechanisms that will be used to obtain feedback on the strategy. EPA recommends that communication strategies:

- Outline the objective and goals of the communication.
- Identify stakeholders.
- Define key messages.
- Pinpoint potential communication methods and vehicles for communicating information and obtaining information from the community for a specific purpose.

When developing a communication strategy, the first step is to determine why the communication is necessary and define its desired objectives, and then to focus on defining the audiences and how to reach them. Keep in mind that the demographics, knowledge, and concerns of the audiences play an important role in defining the key messages. Once the key messages are defined, the outreach vehicle can be determined.

Conducting Community Outreach

The site planning team likely will use several different outreach techniques during the course of the cleanup process. When planning community outreach, EPA generally recommends that the site planning team collaborate with internal and external partners, such as local, state, and tribal officials and departments of health; faith-based organizations; and community groups. It is important to accommodate hearing-impaired or limited English proficiency (LEP)[112] persons in all outreach efforts by providing spoken or sign language interpreters at meetings and translating printed outreach materials. It also is important to ensure that the community understands the concept of vapor intrusion.

Examples of community outreach techniques to consider are described below.

Public Meetings/Gatherings

Public meetings are a useful opportunity to explain environmental conditions at the site, potential health impacts, intended indoor air sampling, and remediation strategies. It may be helpful to hold meetings prior to and following key sampling events to describe sampling strategies and consequent results, respectively. EPA recommends that the meeting include a period to address specific questions from the public regarding sampling results or any other specific concerns, as well as visual aids and maps and spoken or sign language interpreters to facilitate the communication and discussion. The use of a CSM, for example, is useful in public meetings to graphically reinforce the messages. It may be helpful to follow up with meeting participants to inquire about the effectiveness of the meeting and whether it met their needs. Other meeting follow-up activities could include responding to requests for information, distributing meeting notes, and creating a mailing list.

Additional opportunities for the site planning team to communicate with the community in a group setting include public availability sessions and public forums or poster sessions at community group meetings or neighborhood board meetings. These options are a more informal way of interacting with community members and they allow a casual "question and answer" or discussion format as compared to the more formal presentation at a public meeting.

Mass Media

The media can be the best means of reaching a large audience quickly. Extending invitations to the media for important meetings, providing opportunities for media questions to be addressed in a timely manner, and recognizing that the media control the content of

---

[112] Executive Order 13166, *Improving Access to Services for Persons with Limited English Proficiency*, requires federal agencies to examine the services they provide, identify any need for services to those with LEP, and develop and implement a system to provide those services so LEP persons can have meaningful access to them.

their publications all are important considerations when working with the media. The site planning team can work with the Agency's regional site press officer to foster a relationship with the media by sharing the Agency's rationale for its plans and actions. It is appropriate to use the media to publicize a site-related decision, an upcoming meeting, changes in schedule, or changes in activities or expectations. Press releases can be used to inform the media of major site-related milestones.

Fact Sheets

Communities appreciate concise, easy-to-understand, and technically accurate fact sheets on the history of the contamination, chemicals of concern, potential risks, planned cleanup activities, and the vapor intrusion assessment and response actions. Be sure to include who to contact for more information.

Because sites involving vapor intrusion can be complex, it may be useful to include additional information in the fact sheets for home owners and renters, including information about household products that may be potential sources of indoor air contamination, as well as steps that can be taken to minimize these sources. EPA recommends preparing and distributing periodic status updates and fact sheets to concerned community members throughout the cleanup process.

Letters

Whenever there are plans to conduct indoor air sampling, EPA recommends sending a letter to each building owner and renter explaining plans to conduct indoor air sampling and requesting written permission for voluntary access to do so. This letter generally should be in addition to a one-on-one meeting with the building owner or renter to discuss sampling efforts and access agreements in detail (see Section 10.3). EPA also recommends that letters be sent to each building owner and renter to report sampling results in a timely manner (see Section 10.4). These letters and meetings often are part of a larger effort that also includes use of other communication strategies, such as community meetings and in-person visits.

In-person Visits

EPA recommends individual, one-on-one communication with each property owner and renter whenever possible.

- Try to schedule in-person visits with individual property owners and renters. These visits also may include owners and renters of properties located outside the planned investigation area, as applicable. The initial visit can be used to explain sampling plans in more detail, answer questions, and obtain written permission to sample.

- During the visit, the property owner or renter should be briefed about any instructions to follow during sampling activities (for example, keep doors and windows closed during sampling). A general survey of the building should be conducted to determine likely sources of indoor air contaminants.

- The site planning team also should instruct the owners and renters about the sampling devices that will be used, what they look like, where they will be located, and any restrictions to daily activities required as a result of the ongoing sampling activities.

- The site sampling team should arrive on time for the sampling. Someone knowledgeable and able to explain the sampling procedure should accompany the sampling staff. As appropriate, include an interpreter as well.

Information Repository

An information repository can be established and maintained prior to, during, and following site activities and is required for sites where remedial action or removal actions (where on-site action is expected to exceed 120 days) are undertaken pursuant to CERCLA. The information repository should include the administrative record, fact sheets, question-and-answer sheets, and other site-related documents and should be located near the site. However, given the tremendous change in information technology, it may also be appropriate to set up an Internet-based or digital repository (webpages) to share key information. This depends on the community's ability to access and utilize this technology. EPA recommends that community members be made aware of the information repository through the other public outreach mechanisms described above (e.g., local media, newsletters, and public meetings).

Electronic Notification

It also may be useful to establish a registration capability that allows interested community members to sign up for automatic alerts to updates posted on the site website or email listserv.

10.3 Addressing Building Access for Sampling and Mitigation

Gaining access to owner-occupied residences for vapor intrusion sampling and mitigation may be handled differently than for commercial buildings or rental properties. The number of attempts to obtain access to perform a vapor intrusion assessment or install a mitigation system should be consistent with regional practice. In general, more than one attempt for access is recommended. All attempts should be documented using telephone conversation records, emails, or letters sent to home or building owners. EPA recommends that all requests for access, as well as provision of access, be in writing in order to document EPA's due diligence to protect human health at the site. EPA recommends that the site planning team instruct owners or renters about the sampling devices being used, including what they look like, where they will be located and any restrictions to daily activities required due to ongoing sampling.

Owner-Occupied Residences: Allowing EPA to sample or install mitigation systems in an owner-occupied residence is a voluntary action. Owners occupying their homes should be encouraged to take advantage of an offer for an assessment and mitigation system, if necessary.

Rental Properties: Access may be voluntary or involuntary. Site planning teams often deal with both owners and renters when there is a need to sample on, in, or under a rental property. There are different legal and communication issues for owners and renters. For example, the owner is responsible for granting access for sampling and for installation of mitigation measures, if they are necessary; however, if the owner grants access, logistics normally are arranged with the renter. Both the owner and the renter should be apprised of vapor intrusion exposure concerns that have the potential to adversely affect human health, which includes providing sampling results to both parties. If the owner of a rental property refuses access, EPA may require access, in the interest of protecting the occupants, for determining the need for response, choosing a response action, taking a response action, or otherwise enforcing CERCLA or RCRA (EPA 1986, 1987, 2010a).

Nonresidential Buildings: Access may be voluntary or involuntary. Site managers also may need to sample on, in, or under nonresidential buildings, such as schools, libraries, hospitals, hotels, and stores. In these situations, broader outreach to the public may be appropriate in addition to maintaining direct contact with the property owner.

Property Ownership Changes: For owners of homes or buildings who did not provide access for assessment sampling or installation of a mitigation system, EPA recommends that the site planning team make reasonable attempts to track ownership changes, although the appropriate state or local agency or PRP may be in a better position to track this information. For example, reasonable attempts to make contact can be done annually by conducting drive-bys or annual inspections and noting homes or buildings for sale, checking real estate sales listings periodically, or using other mechanisms. Homes that were initially targeted but not sampled can be reconsidered during the review or if there are major changes to the toxicity values for the site contaminants of concern. If ownership changes are noted, appropriate follow-up can be conducted with the new home owner or building owner.

10.4 Communication of Indoor Sampling Efforts and Results

The community involvement plan or public participation plan should pay particular attention to addressing community concerns and participation regarding indoor air and sub-slab sampling. In addition to the general community involvement activities occurring throughout the cleanup process (see Section 10.2), the site planning team may choose to hold a community meeting to discuss indoor sampling efforts and results, and follow up by sending a letter to each home or building owner and renter explaining plans to conduct sampling or providing sampling results. EPA recommends that this letter be in addition to a one-on-one meeting with the building or home owner to discuss access agreements, sampling efforts, and sampling results.

Letters Transmitting Sampling Results

EPA recommends that the site planning team provide validated sampling results in plain English (and translations, if necessary) to property owners and renters within about 30 days of receiving the results. The transmittal letter also should indicate what future actions, if any, are necessary based on the sampling results. Letters reporting sampling results almost certainly will contain site-specific and possibly building-specific information about various issues, such as chemicals of concern, screening levels and mitigation options. However, additional information for inclusion in these letters may include, but is not necessarily limited to:

- Site and Home/Building Information.
    - Site name and location of contamination.

  - Date of sampling.
  - Address of sampled home or building.
  - Locations sampled (both indoor and outdoor).

- Sampling Results
  - Sampling results for chemical(s) of concern.
  - Sampling results for other chemicals, if detected, including an explanation of results believed to be attributable to background sources, if known.
  - Risk-based screening levels used (for example, VISLs described in Section 6.5).
  - Explanation of sampling results, if known.
  - Paragraph listing results, comparison to screening level and explanation.
  - Table of results, including sampling results and screening values, followed by an explanation of results, if known.
  - Simple tabulated and color-coded results (representing exceedances of human health risk levels or no exceedance).

- Diagrams/Illustrations
  - Letters requesting access for sampling may include diagrams and illustrations of sampling devices.
  - Letters giving sampling results or suggesting a mitigation system may include diagrams and illustrations of sampling locations or diagrams of specific mitigation systems (e.g., how a SSD system works and looks).

- Next Steps
  An explanation of what the building owner or resident should expect as a result of the sampling and when he or she can expect to be contacted again. This section may include:
  - Explanation of mitigation process and responsibilities (if applicable).
    -Mitigation options.
    -Timeline for further contact regarding system installation and options.
    If a building mitigation system is recommended on the basis of a risk assessment, EPA recommends that the site planning team explain that the risk calculation reflects many conservative, health-protective factors.

  - EPA recommends that the letter describe actions that property owners and occupants can take to reduce vapor intrusion exposure until mitigation systems are in place.

- Contact information
  - Contact information for a person who can answer questions or supply further explanations should be included in communications with building and homeowners. The location of the site information repository or site website can be included as a resource for public access to more detailed site documents.

10.5 Transmitting Messages Regarding Mitigation Systems

The initial notification to residents or building owners about mitigating vapor intrusion can be delivered in various ways. A primary mechanism is a face-to-face meeting with the building owner or occupant to explain the sampling results and discuss next steps, including installation of a vapor intrusion mitigation system. EPA recommends that this meeting include a member of the site planning team (RPM or OSC and risk assessor, for example), a representative from the local health department or the Agency for Toxic Substances and Disease Registry (ATSDR), and the mitigation contractor scheduler. This meeting could discuss topics such as:

- Sampling Results: Describe where samples were taken and the chemicals of concern, and explain the results as related to site action levels. Any questions related to health impacts or risks can be answered by the risk assessor or health representative at this time.

- Mitigation System Details: Describe the need for a mitigation contractor to visit the residence to identify potential locations for the mitigation system. The property owner will need to be present for the visit and will have input about where the system is installed, if they agree to install such a system. Photos of a mitigation system (piping, system fan, number of holes drilled in the slab, height of the vent on the outside of the residence, etc.) may be helpful. The site planning team representative should also mention the need to sign an additional access agreement approving the installation of the mitigation system described in the meeting.

- Cost of the Mitigation System: Explain which party will pay for installation of the mitigation system (EPA or a PRP, for example) and anticipated property-owner costs. EPA or a PRP may pay for the system installation, and the property owner or PRP may be required to pay for the monthly costs associated with the mitigation system.

- Project Schedule and Next Steps: The meeting may be concluded by giving an overview of the project timeline, including the appointment for the mitigation contractor visit and system installation. The property owner or occupant should be told that the project sample team will need to return after the mitigation system is installed to conduct post mitigation sampling to confirm that the system is lowering the air levels to below site-specific action levels. A follow-up sampling date will be determined and sample results will be communicated to the property owner.

Notification also can be provided through the data transmittal letter. In many cases, however, the decision to install mitigation systems will not have been made prior to the transmittal of sampling results. In these situations, data transmittal letters can convey that EPA is reviewing all data results for the affected area and considering appropriate next steps. Once the decision document is signed, the site planning team can develop and mail a fact sheet to all community members in the affected area, followed by a community meeting.

In addition, if a vapor intrusion mitigation system is installed, EPA recommends that the property owner or renter be informed that the system normally is designed to protect the home or building only against vapor-forming chemicals coming from the subsurface. A vapor intrusion mitigation system generally will not protect the home against continuing indoor sources because vapor intrusion mitigation systems typically are not indoor air filtration systems. For this reason, property owners and occupants should be educated about sources of indoor air contamination in order to minimize their exposures. Further, mitigation systems installed for vapor intrusion will also reduce or prevent naturally occurring radon from entering the building, providing an added benefit to human health.

EPA recommends that current owner-occupants be advised that if they decline an offer to install a vapor mitigation system, they might be responsible for the costs of installing and maintaining their own system if they decide to do so at a later time. The waiver should be documented.

10.6 Addressing Community Involvement at Legacy Sites

Ongoing site activities with assessment components, such as remedial investigations and monitoring, allow EPA to continually evaluate site conditions and adjust cleanup actions as warranted. During periodic reviews or conducting other site activities, such as the FYR required by CERCLA, EPA has evaluated vapor intrusion where appropriate. In some instances, EPA has newly identified vapor intrusion as an exposure pathway. These mature or "legacy" sites present a unique challenge to site planning teams.

Conducting community involvement at legacy sites may be complicated by several factors including:

- A remedy for the control of exposure to volatile organic chemicals already has been installed, proposed, or is under construction as part of the cleanup plan.
- Ownership of properties previously exposed to VOCs has changed hands through resale, foreclosure, or assumption of the property by second-generation homeowners. These owners were not part of any original resolution of exposure issues and in many cases may not be aware that a remediation or treatment was put in place.
- Property owners and other community members who participated in prior cleanup efforts may be reluctant to fully engage with efforts to reopen lines of investigation at their properties.

In these and similar circumstances, the challenge for Agency representatives is to resume contact with communities who have put past difficulties behind them. In many cases, mailing lists are outdated, previous reliable contacts no longer are available, and elected officials may not have institutional memory of the events that prompted the remediation.

<u>Strategies for Revitalizing Community Involvement at Legacy Sites</u>

Every legacy re-entry will be a site-specific situation. Therefore, EPA recommends that events and activities be planned to acknowledge and accommodate the inevitable changes in the makeup of a community. In addition to the communication strategies and community involvement techniques described in Sections 10.1 through 10.5, additional suggestions to ease re-entry and revitalize community involvement at a legacy site include:

- Reassess the community and the site by revisiting the site and the surrounding areas and taking note of new construction.
- Reintroduce yourself and the Agency to current municipal staff and check previously used public venues for viability. Determine if new venues may be closer or more accessible to the community.

- If contacts within the community are still extant, reconnect; ask for updates on the growth and stability of the community. If no viable contacts exist, attempt to cultivate new ones.

- Revise and update mailing lists and fact sheets.

As with all sites affected by vapor intrusion issues, be prepared to meet with property owners door to door and to hold public meetings or forums to explain the current investigation and its importance to ensuring public safety.

10.7 Property Value Concerns for Current and Prospective Property Owners

Property value issues are outside the scope of Agency authority. In general, if asked, EPA recommends that regional staff suggest that prospective buyers and sellers contact real estate professionals and lenders from the local area with questions about property values. If a home owner or renter has questions about vapor intrusion mitigation systems, EPA regions can provide information that explains how vapor intrusion systems are designed to reduce exposure to chemicals found in indoor air and to avert human health-related problems.

10.8 Additional Community Involvement Resources

EPA's Superfund Community Involvement Program:

EPA's Superfund Community Involvement website contains many resources that may be helpful for planning community involvement activities for other cleanup programs. This resource includes a list of regional Superfund community involvement points of contact, a list of technical assistance and training resources, and descriptions and links to community involvement policies, guidance and publications (see http://www.epa.gov/superfund/community/).

EPA's Superfund Community Involvement Toolkit (CI Toolkit):

While targeted to a Superfund Program audience, the CI toolkit may be helpful to a wide variety of users because it is a practical, easy-to-use aid for designing and enhancing community involvement activities and contains tips on how to avoid some of the pitfalls common to the community involvement process. The toolkit enables users to quickly review and adapt a variety of community involvement tools to engage the community during all stages of the cleanup process. Relevant tools include tips for conducting public availability and poster sessions and public meetings, developing fact sheets, working with the media, planning communication strategies, developing a Community Involvement Plan, and establishing an information repository (see http://www.epa.gov/superfund/community/toolkit.htm).

EPA's Community Engagement Initiative:

The OSWER CEI is designed to enhance OSWER and regional offices' engagement with local communities and stakeholders to help them participate meaningfully in government decisions on land cleanup, emergency preparedness and response, and the management of hazardous substances and waste (see http://www.epa.gov/oswer/engagementinitiative/).

11.0 CITATIONS AND REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 2008. *Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites*. Currently available online at: http://www.atsdr.cdc.gov/document/evaluating_vapor_intrusion.pdf

American Society for Testing and Materials (ASTM). 2003. *E 2121: Standard Practice for Installing Radon Mitigation Systems in Existing Low-Rise Residential Buildings.*

American Society for Testing and Materials (ASTM). 1995. *E 1739: Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.*

Association of State and Territorial Solid Waste Management Officials (ASTSWMO). 2009. *Vapor Intrusion Pathway: A Guide for State and Territorial Federal Facilities Managers.* ASTSWMO Policy and Technology Focus Group. Washington, DC. July.

California Environmental Protection Agency (CalEPA). 2011. *Vapor Intrusion Mitigation Advisory*. Department of Toxic Substances Control. Final, Revision 1. October. Currently available online at: http://www.dtsc.ca.gov/AssessingRisk/upload/Final_VIG_Oct_2011.pdf

California Environmental Protection Agency (CalEPA). 2012. *Advisory Active Soil Gas Investigations*. Department of Toxic Substances Control. April. Currently available online at: http://www.dtsc.ca.gov/SiteCleanup/upload/VI_ActiveSoilGasAdvisory_FINAL_043012.pdf

City of Mandan. [2006]. Chapter 21-10: Environmental institutional control ordinance. In: *City of Mandan Municipal Code*, Title 21: Planning and Zoning. Currently available online at: www.cityofmandan.com

Folkes, D.J. and D.W. Kurz. 2002. Efficacy of sub-slab depressurization for mitigation of vapor intrusion of chlorinated organic compounds. In *Proceedings of Indoor Air 2002: The 9th International Conference on Indoor Air and Climate*. June 30-July 5.

Folkes, D.J., J.P. Kurtz, and C. Sanpawanitchakit. 2007. Vapor intrusion as a function of lateral distance from a groundwater plume boundary. In *Proceedings of the Air & Waste Management Association Conference*. September.

Forand S.P., E.L. Lewis-Michl, and M.I. Gomez. 2012. Adverse birth outcomes and maternal exposure to trichloroethylene and tetrachloroethylene through soil vapor intrusion in New York State. In *Environ. Health Perspectives* 120(4): 616-621.

Interstate Technology & Regulatory Council (ITRC). 2007a. *Vapor Intrusion Pathway: A Practical Guideline*. VI-1. ITRC Vapor Intrusion Team. Washington, D.C. January. Currently available online at: http://www.itrcweb.org/documents/VI-1.pdf

Interstate Technology & Regulatory Council (ITRC). 2007b. *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios*. VI-1A. ITRC Vapor Intrusion Team. Washington, D.C. January. Currently available online at: http://www.itrcweb.org/documents/VI-1A.pdf

Izzo, V. J. 1992. *Drycleaners – A Major Source of PCE in Ground Water.* Sacramento: State of California Regional Water Quality Control Board Central Valley Region. March. Currently available online at:
http://www.swrcb.ca.gov/rwqcb5/water_issues/site_cleanup/dry_cleaner_rpt.pdf

Johnson, P.C., and R.A. Ettinger. 1991. Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings. *Environmental Science & Technology 25*:1445-1452.

Lowell, P.S. and B. Eklund. 2004. VOC emission fluxes as a function of lateral distance from the source. In *Environ. Progress* 23(1): 52-58.

Massachusetts Department of Environmental Protection (MADEP). 2011. *Interim Final Vapor Intrusion Guidance*. WSC#-11-435. December. Currently available online at:
http://www.mass.gov/dep/cleanup/iawg.htm

Maupins, K. and D.T. Hitchins. 1998. Reducing employee exposure potential using the ANSI/ASHRAE 110 Method of Testing Performance of Laboratory Fume Hoods as a diagnostic tool. In *American Industrial Hygiene Association Journal* 59(2): 133-138.

McAlary, T.A., J. Provoost, and H.D. Dawson. 2011. Vapor intrusion, In *Dealing with Contaminated Sites. From Theory towards Practical Applications*, Chapter 10. F.A. Swartjes [ed.], Springer Science.

National Conference of Commissioners on Uniform State Laws. 2003. *Uniform Environmental Covenants Act*. Currently available online at:
http://www.epa.gov/superfund/policy/ic/pdfs/kerr_uecalang.pdf

National Research Council (NRC). 2009. *Science and Decisions: Advancing Risk Assessment.* National Academies Press. Washington, D.C. Committee on Improving Risk Analysis Approaches Used by the U.S. EPA.

National Research Council (NRC). 2004. *Contaminants in the Subsurface: Source Zone Assessment and Remediation.* Washington, D.C. Committee on Source Removal of Contaminants in the Subsurface.

New Jersey Department of Environmental Protection (NJDEP). 2012. *Vapor Intrusion Technical Guidance, Version 2.0.* Site Remediation Program. Currently available online at:
http://www.state.nj.us/dep/srp/guidance/vaporintrusion/vig_main.pdf

Odencrantz, J.E., S.C. Thornley, and H. O'Neill. 2009. An evaluation of the performance of multiple passive diffusion devices for indoor air sampling of VOCs. In *Remediation* 19(4): 63-72.

Odencrantz, J.E., H. O'Neill, S.J. Steinmacher, J.D. Case, and P.C. Johnson. 2008. Residential vapor-intrusion evaluation: Long-duration passive sampling vs. short duration active sampling. In *Remediation* 18(4): 49-54.

Rydock, J.P. 2001. Reality-check your fume hoods. In *Today's Chemist at Work.* 10(06): 19-20.

U.S. Department of Defense (DoD). 2009. *DoD Vapor Intrusion Handbook*. January. Currently available online at:
http://www.environmental.usace.army.mil/docs/DoD%20VI%20Handbook%20Final%20Jan%2009.pdf?syspage=documents&id=129239

U.S. Department of the Navy (DoN). 2011a. *Guidance for Environmental Background Analysis, Volume IV: Vapor Intrusion Pathway*. Naval Facilities Engineering Command. Washington, D.C. April. Currently available online at:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/ug-2091-env-vi_bkgd_guid2011.pdf

U.S. Department of the Navy (DoN). 2011b. *Vapor Intrusion Mitigation in Existing Buildings Fact Sheet*. Naval Facilities Engineering Command. Washington, D.C. May. Currently available online at:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/vi_mit_exist_bldgs_fs_201105.pdf

U.S. Department of the Navy (DoN). 2011c. *Vapor Intrusion Mitigation in Construction of New Buildings Fact Sheet*. Naval Facilities Engineering Command. Washington, D.C. August. Currently available online at:
https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_pp/environmental/erb/resourceerb/vi_mit_new_bldg_fs.pdf

U.S. Environmental Protection Agency (EPA). 2013a. *Evaluation of Empirical Data to Support Soil Vapor Intrusion Screening Criteria for Petroleum Hydrocarbon Compounds*. (EPA-510-R-13-001) Office of Underground Storage Tanks. Washington, DC. Currently available online at: http://www.epa.gov/oust/cat/pvi/PVI_Database_Report.pdf

U.S. Environmental Protection Agency (EPA). 2013b. *Technical Basis for the Selection, Design, Installation and Operation & Maintenance of Vapor Intrusion Mitigation Systems* [EPA ###-#-##-###]. In preparation.

U.S. Environmental Protection Agency (EPA). 2013c. *Sampling and Analysis Methods for Vapor Intrusion Investigations* EPA ###-#-##-###]. In preparation.

U.S. Environmental Protection Agency (EPA). 2013d. *Guidance for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* [EPA 530-R-##-###]. In preparation. [http://www.epa.gov/oswer/vaporintrusion/documents/]

U.S. Environmental Protection Agency (EPA). 2013e. *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings Using the Johnson-Ettinger Model* [EPA 530-R-##-###]. In preparation. [http://www.epa.gov/oswer/vaporintrusion/documents/]

U.S. Environmental Protection Agency (EPA). 2012a. *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* [EPA 530-R-10-002]. Currently available online at:
http://www.epa.gov/oswer/vaporintrusion/documents/OSWER_2010_Database_Report_03-16-2012_Final.pdf

U.S. Environmental Protection Agency (EPA). 2012b. *Conceptual Model Scenarios for the Vapor Intrusion Pathway* [EPA 530-R-10-003]. Currently available online at: http://www.epa.gov/oswer/vaporintrusion/documents/vi-cms-v11final-2-24-2012.pdf

U.S. Environmental Protection Agency (EPA). 2012c. *Vapor Intrusion Screening Level (VISL) Calculator, User's Guide.* Currently available online at: http://www.epa.gov/oswer/vaporintrusion/guidance.html

U.S. Environmental Protection Agency (EPA). 2012d. *Assessing Protectiveness at Sites for Vapor Intrusion: Supplement to the Comprehensive Five-Year Review Guidance* [OSWER Directive 9200.2-84]. Currently available online at: http://www.epa.gov/superfund/cleanup/postconstruction/pdfs/VI_FYR_Guidance-Final-11-14-12.pdf

U.S. Environmental Protection Agency (EPA). 2012e. *Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites.* OSWER 9355.0-89. EPA-540-R-09-001. Currently available online at: http://www.epa.gov/superfund/policy/ic/guide/Final%20PIME%20Guidance%20December%202012.pdf

U.S. Environmental Protection Agency (EPA). 2012f. *Institutional Controls: A Guide to Preparing Institutional Control Implementation and Assurance Plans at Contaminated Sites,* OSWER #9200.0-77, EPA-540-R-09-002 Currently available online at: http://www.epa.gov/superfund/policy/ic/guide/ICIAP%20guidance%20(FINAL)%20-%2012.04.2012.pdf

U.S. Environmental Protection Agency (EPA). 2012g. *Fluctuation of Indoor Radon and VOC Concentrations Due to Seasonal Variations.* EPA/600/R-12/673. National Exposure Research Laboratory. Las Vegas, Nevada. September. Currently available online at: http://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=247212&fed_org_id=770&SIType=PR&TIMSType=Published+Report&showCriteria=0&address=nerl/pubs.html&view=citation&sortBy=pubDateYear&count=100&dateBeginPublishedPresented=01/01/2010

U.S. Environmental Protection Agency (EPA). 2011a. *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990-2005): A Compilation of Statistics for Assessing Vapor Intrusion.* EPA 530-R-10-001. Office of Solid Waste and Emergency Response. Washington, D.C. Currently available online at: http://www.epa.gov/oswer/vaporintrusion/documents/oswer-vapor-intrusion-background-Report-062411.pdf

U.S. Environmental Protection Agency (EPA). 2011b. *Exposure Factors Handbook – 2011 Edition.* EPA/600/R-090/052F. Office of Research and Development. Washington, D.C. Currently available online at: http://www.epa.gov/ncea/efh/pdfs/efh-complete.pdf

U.S. Environmental Protection Agency (EPA). 2011c. *Recommended Evaluation of Institutional Controls: Supplement to the "Comprehensive Five-Year Review Guidance."* OSWER Directive

9355.7-18. September. Currently available online at: http://www.epa.gov/superfund/cleanup/postconstruction/641333.pdf

U.S. Environmental Protection Agency (EPA). 2010a. *Clarification of CERCLA Entry Policy.* Office of Enforcement and Compliance Monitoring. Washington, D.C. Memorandum from Kenneth Patterson. March 3. Currently available online at: http://www.epa.gov/compliance/resources/policies/cleanup/superfund/access-clarify-10.pdf

U.S. Environmental Protection Agency (EPA). 2010b. *Review of the Draft 2002 Subsurface Vapor Intrusion Guidance.* Office of Solid Waste and Emergency Response. Washington, D.C. August. Currently available online at: http://www.epa.gov/oswer/vaporintrusion/documents/review_of_2002_draft_vi_guidance_final.pdfU.S. Environmental Protection Agency (EPA). 2010c. *Considering Reasonably Anticipated Future Land Use and Reducing Barriers to Reuse at EPA-lead Superfund Remedial Sites.* OSWER Directive 9355.7-19. March. Currently available online at: http://www.epa.gov/superfund/programs/recycle/pdf/reusedirective.pdf

U.S. Environmental Protection Agency (EPA). 2009a. *Evaluation Report: Lack of Final Guidance on Vapor Intrusion Impedes Efforts to Address Indoor Air Risks.* Report No. 10-P-0042. EPA Office of Inspector General. Washington, D.C. December 2009. Currently available online at: http://www.epa.gov/oig/reports/2010/20091214-10-P-0042.pdf

U.S. Environmental Protection Agency (EPA). 2009b. *Operational and Functional Determination and the Transfer of Fund-lead Vapor Intrusion Mitigation Systems to the State.* OSWER 9200.2-72. April. Currently available online at: http://www.epa.gov/superfund/policy/pdfs/VaporGuidance04092009.pdf

U.S. Environmental Protection Agency (EPA). 2009c. *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment).* EPA 540-R-070-002. Office of Superfund Remediation and Technology Innovation. Washington, DC. Currently available on-line at http://www.epa.gov/oswer/riskassessment/ragsf/index.htm

U.S. Environmental Protection Agency (EPA). 2008a. *Brownfields Technology Primer: Vapor Intrusion Considerations for Redevelopment.* EPA 542-R-08-001. March. Currently available online at: www.brownfieldstsc.org/pdfs/BTSC%20Vapor%20Intrusion%20Considerations%20for%20Redevelopment%20EPA%20542-R-08-001.pdf

U.S. Environmental Protection Agency (EPA). 2008b. *Superfund Environmental Indicators Guidance: Human Exposure Revisions.* Office of Superfund Remediation and Technology Assessment. March. Currently available online at: http://www.epa.gov/superfund/accomp/ei/pdfs/final_ei_guidance_march_2008.pdf

U.S. Environmental Protection Agency (EPA). 2008c. *Engineering Issue: Indoor Air Vapor Intrusion Mitigation Approaches.* EPA/600/R-08-115. Office of Research and Development. October. Currently available online at: http://www.clu-in.org/download/char/600r08115.pdf

U.S. Environmental Protection Agency (EPA). 2007. *Risk Communication in Action: The Risk Communication Workgroup* [EPA/625/R-05/003].

U.S. Environmental Protection Agency (EPA). 2006a. *Guidance on Systematic Planning Using the Data Quality Objectives Process (EPA QA/G-4)*. EPA/240/B-06/001. Office of Environmental Information. Washington, D.C. February. Currently available online at: http://www.epa.gov/quality/qs-docs/g4-final.pdf

U.S. Environmental Protection Agency (EPA). 2006b. *Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Subslab Air Samples*. EPA 600-R-05-147. March. Currently available online at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000D268.txt

U.S. Environmental Protection Agency (EPA). 2006c. *In Situ Treatment Technologies for Contaminated Soil*. EPA 542/F-06/013. Office of Solid Waste and Emergency Response. Washington, DC. November. Currently available on-line at: http://www.cluin.org/download/remed/542f06013.pdf

U.S. Environmental Protection Agency (EPA). 2005. *Guidance for Evaluating Landfill Gas Emissions from Closed or Abandoned Facilities*. Currently available online at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1000BRN.txt

U.S. Environmental Protection Agency (EPA). 2003. *Human Health Toxicity Values in Superfund Risk Assessments* [OSWER Directive 9285.7-53], December 5. Currently available online at: http://www.epa.gov/oswer/riskassessment/pdf/hhmemo.pdf

U.S. Environmental Protection Agency (EPA). 2002a. *Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers* [EPA542-S-02-011]. Currently available online at: http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf

U.S. Environmental Protection Agency (EPA). 2002b. *Office of Inspector General Recommendations Concerning RCRA Corrective Action*. Office of Solid Waste. Washington, D.C. Currently available online at: http://www.epa.gov/osw/hazard/correctiveaction/pdfs/eiigmemo.pdf

U.S. Environmental Protection Agency (EPA). 2002c. *OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)*. EPA 530-D-02-004. Office of Solid Waste and Emergency Response. Washington, D.C.. November. Currently available online at: http://www.epa.gov/osw/hazard/correctiveaction/eis/vapor.htm

U.S. Environmental Protection Agency (EPA). 2002d. *Superfund Response Actions: Temporary Relocations Implementation Guidance*. OSWER Directive 9230.0-97. Office of Solid Waste and Emergency Response. Washington, DC. April. Currently available on-line at: http://www.epa.gov/superfund/community/relocation/tempreloc.pdf

U.S. Environmental Protection Agency (EPA). 2001. *Comprehensive Five-Year Review Guidance*. OSWER 9355.7-03B-P. EPA 540-R-01-007. June. Currently available online at: http://www.epa.gov/superfund/cleanup/postconstruction/5yr.htm

U.S. Environmental Protection Agency (EPA). 2000. *Data Quality Objectives Process for Hazardous Waste Site Investigations, Final [EPA QA/G-4HW]*, January. Currently available online at: http://www.epa.gov/quality/qs-docs/g4hw-final.pdf

U.S. Environmental Protection Agency (EPA). 1999a. *Interim-Final Guidance for RCRA Corrective Action Environmental Indicators*. Office of Solid Waste. Washington, D.C.. February 5. Currently available online at: http://www.epa.gov/osw/hazard/correctiveaction/eis/ei_guida.pdf

U.S. Environmental Protection Agency (EPA). 1999b. *A Guide to Preparing Superfund Proposed Plans, Records of Decision, and Other Remedy Selection Documents*. EPA 540-R-98-031. Office of Solid Waste and Emergency Response. Washington, D.C.. July. Currently available online at: http://www.epa.gov/superfund/policy/remedy/rods/pdfs/guide_decision_documents_071999.pdf

U.S. Environmental Protection Agency (EPA). 1995. *Land Use in CERCLA Remedy Selection Process*. OSWER Directive 9355.7-04. May. Currently available online at: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=91016C7A.txt

U.S. Environmental Protection Agency (EPA). 1993a. *Radon Reduction Techniques for Existing Detached Houses: Technical Guidance (Third Edition) for Active Soil Depressurization Systems*. EPA 625-R-93-011. October.

U.S. Environmental Protection Agency (EPA). 1993b. *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with VOCs in Soils.*

U.S. Environmental Protection Agency (EPA). 1992a. *Guidance for Data Usability in Risk Assessment, Part A.* Currently available online at: http://www.epa.gov/oswer/riskassessment/datause/parta.htm

U.S. Environmental Protection Agency (EPA). 1992b. *Early Action and Long-term Action Under SACM – Interim Guidance*. Publication 9203.1-051. Office of Solid Waste and Emergency Response. Washington, D.C.. December.

U.S. Environmental Protection Agency (EPA). 1991a. *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*. Office of Solid Waste and Emergency Response. Washington, D.C.. April. OSWER Directive 9355.0-30. Currently available online at: http://www.epa.gov/oswer/riskassessment/pdf/baseline.pdf.

U.S. Environmental Protection Agency (EPA). 1991b. *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part B, Development of Preliminary Remediation Goals), Interim*. EPA 540-R-92-003. Office of Emergency and Remedial Response. Washington, DC. December. Currently available on-line at http://www.epa.gov/oswer/riskassessment/ragsb/index.htm

U.S. Environmental Protection Agency (EPA). 1987. *Entry and Continued Access Under CERCLA*. Memorandum 9829.2. Office of Enforcement and Compliance Monitoring. Washington, D.C. June 5. Currently available online at: http://www.epa.gov/compliance/resources/policies/cleanup/superfund/cont-access-mem.pdf

U.S. Environmental Protection Agency (EPA). 1986. *Inspection Authority Under Section 3007 of RCRA*. Office of General Counsel. Washington, D.C. Memorandum from Francis Blake. Currently available online at: http://www.epa.gov/compliance/resources/policies/civil/rcra/auths3007rcra-mem.pdf

U.S. Environmental Protection Agency, Environmental Response Team (EPA-ERT). 2012. *Standard Operating Procedures, Trace Atmospheric Gas Analyzer (TAGA) IIE Operation (SOP 1711)*. October 22. Currently available online at: http://www.epaosc.org/sites/2107/files/1711-r00.pdf

U.S. Environmental Protection Agency, Environmental Response Team (EPA-ERT). 2001a. *Standard Operating Procedures, Groundwater Well Sampling (SOP 2007)*. April 16. Currently available online at: http://www.epaosc.org/sites/2107/files/2007-R00.pdf

U.S. Environmental Protection Agency, Environmental Response Team (EPA-ERT). 2001b. *Standard Operating Procedures, Soil Sampling (SOP 2012)*. July 11. Currently available online at: http://www.epaosc.org/sites/2107/files/2012-r10.pdf

U.S. Environmental Protection Agency, Region 9 (EPA-Region 9). 2010. R9's *"RARE"Opportunity to Improve Vapor Intrusion Indoor Air Investigations*. EPA Vapor Intrusion Forum. June 14.

U.S. Postal Service (USPS). 2009. *Vapor Intrusion Guidance, Volume 1*. September. Currently available online at: http://www.optexcorp.com/uspsess/documents/Vapor%20Intrusion%20Doc.pdf

APPENDIX A
CHEMICALS OF POTENTIAL CONCERN FOR VAPOR INTRUSION

This appendix identifies chemicals that meet the criteria for vapor-forming chemicals described in Section 3.1. These criteria do not include a consideration of whether these chemicals are regulated pursuant to CERCLA, as amended, or RCRA, as amended. The list of vapor-forming substances warranting consideration for potential vapor intrusion may be modified in the future as toxicity values are updated.

EPA recommends that the following chemicals be routinely evaluated during vapor intrusion assessments conducted in accordance with the Final VI Guidance, when they are present as subsurface contaminants.

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Acetaldehyde	75-07-0
Acetone	67-64-1
Acetone Cyanohydrin	75-86-5
Acetonitrile	75-05-8
Acrolein	107-02-8
Acrylonitrile	107-13-1
Allyl Chloride	107-05-1
Aroclor 1221	11104-28-2
Aroclor 1232	11141-16-5
Azobenzene	103-33-3
Benzene	71-43-2
Benzyl Chloride	100-44-7
Biphenyl, 1,1'-	92-52-4
Bis(2-chloro-1-methylethyl) ether	108-60-1
Bis(2-chloroethyl)ether	111-44-4
Bis(chloromethyl)ether	542-88-1
Bromo-2-chloroethane, 1-	107-04-0
Bromobenzene	108-86-1
Bromochloromethane	74-97-5
Bromodichloromethane	75-27-4
Bromomethane	74-83-9
Butadiene, 1,3-	106-99-0
Carbon Disulfide	75-15-0
Carbon Tetrachloride	56-23-5
Chloro-1,1-difluoroethane, 1-	75-68-3
Chloro-1,3-butadiene, 2-	126-99-8
Chlorobenzene	108-90-7
Chlorobenzotrifluoride, 4-	98-56-6

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Chlorodifluoromethane	75-45-6
Chloroform	67-66-3
Chloromethane	74-87-3
Chloromethyl Methyl Ether	107-30-2
Chloropicrin	76-06-2
Cumene	98-82-8
Cyanide (CN-)	57-12-5
Cyclohexane	110-82-7
Cyclohexene	110-83-8
Dibromo-3-chloropropane, 1,2-	96-12-8
Dibromochloromethane	124-48-1
Dibromoethane, 1,2-	106-93-4
Dibromomethane (Methylene Bromide)	74-95-3
Dichloro-2-butene, 1,4-	764-41-0
Dichloro-2-butene, cis-1,4-	1476-11-5
Dichloro-2-butene, trans-1,4-	110-57-6
Dichlorobenzene, 1,2-	95-50-1
Dichlorobenzene, 1,4-	106-46-7
Dichlorodifluoromethane	75-71-8
Dichloroethane, 1,1-	75-34-3
Dichloroethane, 1,2-	107-06-2
Dichloroethylene, 1,1-	75-35-4
Dichloroethylene, 1,2-trans-	156-60-5
Dichloropropane, 1,2-	78-87-5
Dichloropropene, 1,3-	542-75-6
Dicyclopentadiene	77-73-6
Difluoroethane, 1,1-	75-37-6
Dihydrosafrole	94-58-6
Diisopropyl Ether	108-20-3
Dimethylvinylchloride	513-37-1
Epichlorohydrin	106-89-8
Epoxybutane, 1,2-	106-88-7
Ethyl Chloride	75-00-3
Ethyl Methacrylate	97-63-2
Ethylbenzene	100-41-4
Ethyleneimine	151-56-4
Ethylene Oxide	75-21-8
Hexamethylene Diisocyanate, 1,6-	822-06-0
Hexane, N-	110-54-3

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Hexanone, 2-	591-78-6
Hydrogen Cyanide	74-90-8
Mercury (elemental)	7439-97-6
Methacrylonitrile	126-98-7
Methyl Acrylate	96-33-3
Methyl Ethyl Ketone (2-Butanone)	78-93-3
Methyl Isobutyl Ketone (4-methyl-2-pentanone)	108-10-1
Methyl Isocyanate	624-83-9
Methyl Methacrylate	80-62-6
Methyl Styrene (Mixed Isomers)	25013-15-4
Methyl tert-Butyl Ether (MTBE)	1634-04-4
Methylene Chloride	75-09-2
Naphthalene	91-20-3
Nitrobenzene	98-95-3
Nitromethane	75-52-5
Nitropropane, 2-	79-46-9
Nitroso-di-N-butylamine, N-	924-16-3
Nonane, n-	111-84-2
Pentane, n-	109-66-0
Phosgene	75-44-5
Propionaldehyde	123-38-6
Propyl benzene	103-65-1
Propylene	115-07-1
Propylene Glycol Dinitrate	6423-43-4
Propylene Oxide	75-56-9
Styrene	100-42-5
Tetrachloroethane, 1,1,1,2-	630-20-6
Tetrachloroethane, 1,1,2,2-	79-34-5
Tetrachloroethylene	127-18-4
Tetrafluoroethane, 1,1,1,2-	811-97-2
Tetrahydrofuran	109-99-9
Toluene	108-88-3
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1
Trichlorobenzene, 1,2,4-	120-82-1
Trichloroethane, 1,1,1-	71-55-6
Trichloroethane, 1,1,2-	79-00-5
Trichloroethylene	79-01-6
Trichlorofluoromethane	75-69-4
Trichloropropane, 1,2,3-	96-18-4

Chemical of Potential Concern for Vapor Intrusion	CAS No.
Trichloropropene, 1,2,3-	96-19-5
Triethylamine	121-44-8
Trimethylbenzene, 1,2,3-	526-73-8
Trimethylbenzene, 1,2,4-	95-63-6
Vinyl Acetate	108-05-4
Vinyl Bromide	593-60-2
Vinyl Chloride	75-01-4
Xylene, p-	106-42-3
Xylene, m-	108-38-3
Xylene, o-	95-47-6
Xylenes	1330-20-7

APPENDIX B
RECOMMENDED SUBSURFACE-TO-INDOOR AIR ATTENUATION FACTORS

B.1.0. INTRODUCTION

This Final VI Guidance includes recommended medium-specific (groundwater, soil gas, and indoor air) Vapor Intrusion Screening Levels (VISLs) that are intended to help identify those sites likely to pose a health concern from vapor intrusion and identify areas or buildings that may warrant further investigation of the vapor intrusion pathway. These VISLs are recommended for use in evaluating the concentrations of vapor-forming chemicals measured in groundwater, "near-source" exterior soil gas, and sub-slab soil gas in residential and non-residential settings where the potential for vapor intrusion is under investigation.

The subsurface VISLs are developed considering a generic conceptual model for vapor intrusion consisting of a groundwater or vadose zone source of vapor-forming chemicals that diffuse upwards through unsaturated soils towards the surface and enter buildings. The underlying assumption for this generic model is that subsurface characteristics will tend to reduce or attenuate vapor concentrations as vapors migrate upward from the source and into structures. Section 6.5.1 describes this conceptual model further. In general, it is recommended that the user consider whether the assumptions underlying the generic conceptual model are applicable at each site. The *Vapor Intrusion Screening Level (VISL) Calculator User's Guide* (EPA 2012c) provides additional information about the technical basis for deriving the VISLs.

Comparison of sampling results to medium-specific VISLs comprises one line of evidence in the multiple-lines-of-evidence approach described in the Final VI Guidance. The subsurface (groundwater and soil gas) VISLs (C_{VISL}) are calculated using risk-based, screening levels for indoor air ($C_{target,ia}$) and a medium-specific, subsurface-to-indoor air attenuation factor (α_{VI}), as follows:

$$C_{VISL} = \frac{C_{target,ia}}{\alpha_{VI}} \qquad \text{Equation 1}$$

The risk-based, indoor air screening levels ($C_{target,ia}$) are calculated according to the guidance provided in Risk Assessment Guidance for Superfund (RAGS) Part F (EPA 2009) as implemented in EPA's Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/). The medium-specific, attenuation factors (α_{VI}) recommended for calculating the subsurface VISLs are derived from information in *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012a).

This appendix describes the technical basis for the selection of the subsurface-to-indoor air attenuation factors (α_{VI}) that are recommended for use in calculating the VISLs for groundwater, sub-slab soil gas, "near-source" exterior soil gas, and crawl space air, according to Equation 1.

B.2.0. DEFINITION AND DESCRIPTION OF ATTENUATION FACTOR

Vapor attenuation refers to the reduction in concentration of vapor-forming chemicals that occurs during vapor migration in the subsurface, coupled with the dilution that can occur when the vapors enter a building and mix with indoor air (Johnson and Ettinger 1991). The aggregate effect of these physical and chemical attenuation mechanisms can be quantified through the use of a subsurface-to-indoor air vapor intrusion attenuation factor (α_{VI}), which is defined as the ratio of the indoor air concentration arising from vapor intrusion ($C_{IA\text{-}VI}$) to the subsurface vapor concentration (C_{sv}) at the source or a depth of interest in the vapor migration pathway (EPA 2012a):

$$\alpha_{VI} = \frac{C_{IA-VI}}{C_{SV}} \qquad \text{Equation 2}$$

As defined here, the vapor attenuation factor is an inverse measurement of the overall dilution that occurs as vapors migrate from a point of measurement in the subsurface into a building; i.e., attenuation factor values decrease with increasing dilution of vapor concentration.

Subsurface vapor concentrations (C_{SV}) may be measured directly under a building (often called sub-slab soil gas or just sub-slab), measured exterior to a building at any depth in the unsaturated zone (often called exterior soil gas), or derived from groundwater concentrations by converting the dissolved concentration to a vapor concentration assuming equilibrium conditions (i.e., by multiplying the groundwater concentration by the chemical's dimensionless Henry's law constant for the groundwater temperature *in situ*) (EPA 2001; Appendix D).

Subfloor vapor concentrations may also be measured in building crawl spaces. Although crawl space samples are not strictly subsurface samples, they represent the vapor concentration underlying a building's living space. Thus, crawl space samples may be evaluated in a manner similar to subsurface vapor samples.

B.3.0. RECOMMENDED ATTENUATION FACTORS

This section summarizes the technical basis and rationale for EPA's recommended attenuation factors for groundwater, sub-slab soil gas, exterior soil gas, and crawl space air, as follows:

- Section B.3.1 summarizes EPA's database of empirical attenuation factor values and the results of analyzing that database.
- Section B.3.2 identifies the recommended empirically based attenuation factors for groundwater.
- Section B.3.3 identifies the recommended attenuation factor for sub-slab soil gas and presents a theoretical analysis that supports the selection of the recommended empirically based value.

- Section B.3.4 recommends a generic attenuation factor for exterior soil gas and discusses its basis, justification, and limited applications.
- Section B.3.5 identifies the recommended attenuation factor for crawlspace vapor.
- Section B.3.6 presents a reliability analysis of the recommended generic attenuation factors.

B.3.1 EPA'S VAPOR INTRUSION DATABASE (EPA 2012A)

The information in *EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* (EPA 2012a) is used to derive recommended attenuation factor values for use in evaluating subsurface sample concentrations collected as part of vapor intrusion investigations. EPA's vapor intrusion database consists of numerous pairings of concentrations in indoor air and subsurface samples (groundwater, sub-slab soil gas, exterior soil gas, and crawlspace vapor) from actual sites. It represents the most comprehensive compilation of vapor intrusion data for chlorinated hydrocarbons (CHCs) available at this time.

EPA's vapor intrusion database was analyzed and screened to reduce the impacts of background sources to indoor air concentrations. The resulting data distributions are considered representative of vapor intrusion of CHCs from subsurface sources into residential buildings for most conditions. These distributions serve as the basis for identifying the high-end (conservative) attenuation factors for those media.

Table B-1 and Figure B-1 (Table 19 and Figure 34, respectively, in EPA (2012a)) present and compare the distributions of the attenuation factors (groundwater, exterior soil gas, sub-slab soil gas, and crawl space) that remain after applying the respective source strength and indoor air screens considered most effective at reducing the influence of background contributions to indoor air concentrations. These data demonstrate that the attenuation factor distributions obtained for groundwater, sub-slab soil gas, and crawl spaces for multiple buildings and sites are consistent with the conceptual model for vapor intrusion, which predicts that greater attenuation is expected with greater depths to the vapor sources or vapor samples. As shown in Table B-1 and Figure B-1, the paired groundwater–indoor air data generally exhibit greater attenuation (lower attenuation factors) than the paired sub-slab soil gas–indoor air data, which in turn exhibit greater attenuation than the paired crawl space-indoor air data.

B.3.2 RECOMMENDED ATTENUATION FACTORS FOR GROUNDWATER

To account for the inherent temporal and spatial variability in indoor air and subsurface vapor concentrations, the 95th percentile value of the "source-screened" groundwater data subset in EPA 2012a is recommended as a reasonably conservative generic attenuation factor. **Thus, for groundwater, the recommended generic attenuation factor (α_{gw}) is 0.001.** This value is considered to apply for any soil type in the vadose zone (excepting where preferential vapor pathways are present) in cases where the groundwater is greater than five feet below the ground surface. If the depth to groundwater is less than five feet below the building foundation, investigation of the indoor space is recommended, as there is potential for contaminated groundwater to contact the building foundation, either because the capillary fringe intersects the building foundation or groundwater fluctuations results in groundwater wetting the foundation.

Table B-2 (Table 13 in EPA (2012a)) provides statistics and Figure B-2 (Figure 28 in EPA (2012a)) shows box-and-whisker plots for individual sites compared with the statistics for the combined set of screened groundwater attenuation factors. This table and figure show that the 95th percentile value of the combined groundwater-indoor air measurements is considered appropriate for estimating reasonable worse-case indoor air concentrations that might be observed at a site due to vapor intrusion. The majority of sites and buildings would be expected to exhibit lower indoor air concentrations.

A factor that commonly results in greater attenuation (lower attenuation factors) is the presence of laterally extensive, unfractured fine-grained sediment in the vadose zone. Table B-3 (Table 14 in EPA (2012a)) provides selected statistics and Figure B-3 (Figure 29 in EPA (2012a)) shows the box-and-whisker plots for the groundwater attenuation factors for three soil types. Comparing each descriptive statistic (except for the 25th percentile values) indicates that the attenuation factor values for residences overlying soils classified as "very coarse" generally are larger than those for residences overlying soils classified as "coarse," which are larger than those for soils classified as "fine." This pattern is consistent with the conceptual model for vapor intrusion; smaller attenuation factors, which indicate greater reduction in vapor concentration, would be expected in vadose zones with finer-grained soils, when all other factors (e.g., depth to groundwater, biodegradability of the volatile chemicals) are the same. The 95th percentile value of the coarse-grained soil is equal to the generic value, as expected, since coarse-grained soil provide low resistance to vapor transport and thus would be expected to yield high-valued attenuation factors. Where fine-grained sediments underlay buildings, however, more attenuation is expected and observed in the database. **Thus, a semi-site-specific attenuation factor of 0.0005 may be used at sites where laterally extensive fine-grained sediment has been demonstrated through site-specific sampling to underlay buildings being investigated for vapor intrusion.**

B.3.3 RECOMMENDED GENERIC ATTENUATION FACTOR FOR SUB-SLAB SOIL GAS

To account for the inherent temporal and spatial variability in indoor air and subsurface vapor concentrations, the 95th percentile value of the "source-screened" sub-slab data subset in EPA (2012a) is recommended as a reasonably conservative generic attenuation factor. Thus, **for sub-slab soil gas, the recommended generic attenuation factor (α_{gw}) is 0.03.**

The selection of this value can be supported by theoretical analysis. Specifically, a simple mass balance analysis, assuming a well-mixed interior volume and steady-state conditions, indicates that the theoretical (true) sub-slab soil gas attenuation factor can be expressed as the ratio of the soil gas entry rate to the building ventilation rate (Song et al., 2011; EPA 2012a) for cases where there is no background contribution to the indoor air concentration. Using median values for residential building volume and air exchange rate (395 m^3 and 0.45 ACH, respectively) provided in the *Exposure Factors Handbook 2011 Edition* (EPA, 2011) and a mid-range value of 5 L/min for soil gas entry rate in sandy materials (EPA 2002, Appendix G), the central tendency value of the sub-slab soil gas attenuation factor (according to Equation 4a), is expected to be approximately 0.002. Using upper-end (10th percentile) values for residential building volume and air exchange rate (154 m^3 and 0.18 ACH, respectively (EPA 2011)) and soil gas entry rate (10 L/min), an upper-end value of 0.02 for the sub-slab soil gas attenuation factor is obtained. These values agree well with the 95^{th} percentile and 50^{th} percentile (median) values (0.03 and 0.003, respectively) obtained from the source-screened data. These calculations buttress the conclusion that the sub-slab attenuation factor distributions summarized in EPA's vapor intrusion database report can be considered representative of vapor intrusion of CHCs into residential buildings for most conditions.

Table B-4 (Table 10 in EPA (2012a)) provides statistics and Figure B-4 (Figure 25 in EPA (2012a)) shows box-and-whisker plots for individual sites compared with the statistics for the combined set of screened sub-slab attenuation factors. This table and figure show that the 95^{th} percentile value of the combined sub-slab-indoor air measurements is considered appropriate for estimating reasonable worse-case indoor air concentrations that might be observed at a site due to vapor intrusion. The majority of sites and buildings would be expected to exhibit lower indoor air concentrations.

B.3.4 RECOMMENDED ATTENUATION FACTOR FOR "NEAR-SOURCE" EXTERIOR SOIL GAS

Based upon the conceptual model for vapor intrusion, the attenuation factors for exterior soil gas data would be expected to be less than those for sub-slab soil gas, because the former includes an additional contribution from attenuation through the vadose zone, and greater than those for groundwater vapors for a given building at a site where groundwater is the primary subsurface source of vapors. The distributions of exterior soil gas attenuation factors shown in Table B-1 and Figure B-1 do not exhibit this expected relationship. In addition, a comparison of exterior soil gas to sub-slab soil gas concentrations for buildings where both types of samples were collected, shown in Figure B-5 (see Figure 6 in EPA (2012a)), suggests that a substantial proportion of the exterior soil gas data in the database, particularly shallow soil gas data, may not be representative of soil gas concentrations directly underneath a building. On this basis, shallow exterior soil gas sampling data generally are not recommended for purposes of estimating indoor air concentrations and the exterior soil gas attenuation factors in Table B-1 are not recommended for use in deriving generic attenuation factors.

Based upon the data in Figure B-5, "deep" exterior soil gas data appear to more reliably reflect sub-slab concentrations beneath buildings. On this basis, "near-source" soil gas sampling data (i.e., collected in the vadose zone immediately above each vapor source) generally are allowed for purposes of estimating indoor air concentrations. However, the same conservative attenuation factor value for sub-slab soil gas is recommended for use with "near-source" exterior soil gas data for this purpose. **Thus, for "near-source" exterior soil gas, the recommended generic attenuation factor is 0.03.**

B.3.5 RECOMMENDED ATTENUATION FACTOR FOR CRAWLSPACE VAPOR

The distribution of attenuation factors presented in Figure B-1 show that attenuation between building crawlspaces and living spaces is limited. To account for the inherent temporal and spatial variability in indoor air and crawlspace vapor concentrations, the 95th percentile value of the "indoor air-screened" crawlspace data subset in EPA (2012a) is recommended as a reasonably conservative generic attenuation factor. **Thus, for crawl space vapor the recommended generic attenuation factor is 1.0** (0.9 rounded up to 1.0).

B.3.6 RELIABILITY ANALYSIS OF THE RECOMMENDED SUBSURFACE-TO-INDOOR AIR GENERIC ATTENUATION FACTORS

An analysis was performed to determine the reliability of these recommended attenuation factors for screening in residences in EPA's vapor intrusion data base with measured indoor air concentrations exceeding target levels corresponding to a cancer risk of 10^{-6} and a hazard quotient of 1. The reliability analysis was performed separately for each medium by determining the number of correct assessments and the number of false negatives for a range of attenuation factors.

For the purposes of this analysis:

- A correct assessment is deemed to occur either: (1) when a chemical's measured indoor air concentration exceeds the target level and the measured subsurface vapor concentration also exceeds the appropriate medium-specific VISL calculated using the specified generic attenuation factor, or (2) when a chemical's measured indoor air concentration is below the target level and the measured subsurface vapor concentration also is below the appropriate medium-specific VISL calculated using the recommended generic attenuation factor. Correct assessments in this analysis represent a correct decision based on subsurface concentration data regarding the potential for vapor intrusion to pose indoor air concentrations that exceed target risk-based concentrations in affected buildings.

- A false negative is deemed to occur when a chemical's measured indoor air concentration exceeds the target level, but the measured subsurface vapor concentration does not exceed the appropriate medium-specific VISL calculated using the specified generic attenuation factor. False negatives in this analysis represent the potential for making an incorrect decision based on subsurface concentration data regarding the potential for vapor intrusion to pose indoor air concentrations that exceed target risk-based concentrations in affected buildings.

This assessment uses the Data Consistency Subset of the EPA's vapor intrusion database for residential buildings (i.e., before screening to minimize the impacts of background contributions to indoor air as described in EPA (2012a)). This subset was chosen to allow for the possibility that background indoor air contributions were incorrectly identified and removed from further analysis in the "source-screened" data subsets presented in EPA (2012a). Thus, false negatives may appear if indoor or ambient (outdoor) sources of VOCs are present and they exceed the indoor air target level. This choice of datasets provides a conservative estimate of the frequency of false negatives identified by this reliability analysis. Even lower rates of false negatives would be obtained when considering the "source-screened" data subsets, described in EPA (2012a), in which the impacts of background contributions to indoor air are minimized.

The results of this assessment are shown in Figures B-6 through B-8 for sub-slab soil gas, groundwater, and exterior soil gas. The essential results are as follows:

- The recommended generic attenuation factors yield low rates of false negatives (< 2%) for all three media when individual pairs of samples are evaluated together.

- The recommended generic attenuation factors for groundwater, exterior soil gas, and sub-slab soil gas provide generally high rates of correct assessments when individual pairs of samples are evaluated together: 78% for groundwater; 76% for exterior soil gas; and 87% for sub-slab soil gas. Higher rates of correct assessments are expected for sub-slab soil gas than for the other subsurface media, likely due to the closer spatial correspondence of building sub-slab soil gas and indoor air samples.

- The rates of correct assessments appear to level off in Figure B-6 through B-8 at about the point on the x-axis where the recommended generic attenuation factors occur.

Significantly higher rates of a correct assessment are reasonably anticipated to be realized by following the Final VI Guidance. Specifically, collecting multiple samples to characterize spatial and temporal variability, collecting multiple lines of additional evidence, and weighing this information together should significantly reduce the "error rates" estimated in this reliability analysis, which are based upon comparison of individual pairs of indoor air and subsurface sample concentrations.

As previously stated, the Final VI Guidance includes subsurface VISLs that are intended to help identify those sites with the potential to pose a vapor intrusion concern. The reliability analysis described above suggests the recommended attenuation factors, on which the recommended VISLs are based, should provide a reasonably small probability of 'screening out' sites that pose a vapor intrusion concern and a high probability of correctly identifying sites or buildings that may pose a vapor intrusion concern.

B.4.0. CONSIDERATIONS FOR NON-RESIDENTIAL BUILDINGS

The recommended attenuation factors (see Sections B.3.2 through B.3.5) are proposed for use for non-residential buildings as well as residential buildings. The rationale is two-fold:

- In many geographic locations, some commercial enterprises have been established in converted residential buildings. Although used for commercial purposes, such buildings can reasonably be expected to exhibit similar susceptibility to vapor intrusion and similar interior mixing and dilution (and, hence, similar attenuation factors) as residential buildings represented in EPA's vapor intrusion database.

- There is currently only limited empirical data for purposes of deriving attenuation factors for the many types of non-residential buildings, other than converted residences, which are expected to exhibit a wide range of attenuation factors. In particular, there is limited empirical data pertaining to soil gas entry rates for conventional commercial or industrial buildings.

There are theoretical considerations to support expectations that larger non-residential buildings that are constructed on thick slabs will have lower attenuation factors than residential buildings. These considerations include:

- Given that the size (e.g., interior height and footprint area) and air exchange rate tend to be larger for many non-residential buildings (see, for example, Table B-5), it is expected that building ventilation rates for many non-residential buildings would be higher than those for residential buildings. A higher ventilation rate is expected to result in greater overall vapor dilution as vapors migrate from a subsurface source into a building. On this basis, many non-residential buildings would be expected to have lower attenuation factors than those for residential buildings, all else being equal.

- Comparing buildings with slab-on-grade construction, non-residential buildings tend to have thicker slabs than residential buildings. With thicker slabs, a given amount of differential settling would be expected to lead to less cracking in the slab and would be less likely to create cracks that extend across the entire slab thickness. Buildings with thicker slabs would, therefore, be expected to exhibit lower soil gas entry rates, all else being equal.

Where appropriate, EPA may consider appropriate building-specific data, information, and analysis when evaluating vapor intrusion into large non-residential buildings.

B.5.0. CITATIONS

Johnson, P.C., and R.A. Ettinger. 1991. Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings. *Environmental Science & Technology 25*:1445-1452.

Song, S., F. C. Ramacciotti, B. A. Schnorr, M. Bock, and C.M. Stubbs. 2011. Evaluation of EPA's Empirical Attenuation Factor Database. *EM, Air & Waste Management Association.* February.

U.S. Environmental Protection Agency (EPA). 2012a. *U.S. EPA's Vapor Intrusion Database: Evaluation and Characterization of Attenuation Factors for Chlorinated Volatile Organic Compounds and Residential Buildings* [EPA 530-R-10-002]. Currently available online at http://www.epa.gov/oswer/vaporintrusion/documents/OSWER_2010_Database_Report_03-16-2012_Final.pdf

U.S. Environmental Protection Agency (EPA). 2012b. *Conceptual Model Scenarios for the Vapor Intrusion Pathway.* EPA 530-R-10-003. Currently available online at http://www.epa.gov/oswer/vaporintrusion/documents/vi-cms-v11final-2-24-2012.pdf

U.S. Environmental Protection Agency (EPA). 2012c. *Vapor Intrusion Screening Level (VISL) Calculator, User's Guide.* Currently available online at: http://www.epa.gov/oswer/vaporintrusion/guidance.html

U.S. Environmental Protection Agency (EPA). 2011. *Exposure Factors Handbook – 2011 Edition.* EPA 600/R-090/052. Office of Research and Development. Washington, DC. Currently available online at http://www.epa.gov/ncea/efh/pdfs/efh-complete.pdf

U.S. Environmental Protection Agency (EPA). 2009. *Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment).* EPA 540-R-070-002. Office of Superfund Remediation and Technology Innovation. Washington, DC. Currently available on-line at http://www.epa.gov/oswer/riskassessment/ragsf/index.htm

U.S. Environmental Protection Agency (EPA). 2002. *OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance).* EPA 530-D-02-004. Office of Solid Waste and Emergency Response. Washington, D.C.. November. Currently available online at: http://www.epa.gov/osw/hazard/correctiveaction/eis/vapor.htm

U.S. Environmental Protection Agency (EPA). 2001. *Fact Sheet, Correcting the Henry's Law Constant for Soil Temperature.* Office of Solid Waste and Emergency Response, Washington, DC. Currently available on-line at http://www.epa.gov/oswer/riskassessment/airmodel/pdf/factsheet.pdf

TABLE B 1.
DESCRIPTIVE STATISTICS SUMMARIZING ATTENUATION FACTOR DISTRIBUTIONS FOR GROUNDWATER, EXTERIOR SOIL GAS, SUB SLAB SOIL GAS, AND CRAWL SPACE VAPOR AFTER APPLICATION OF THE DATABASE SCREENS CONSIDERED MOST EFFECTIVE AT MINIMIZING THE INFLUENCE OF BACKGROUND SOURCES ON INDOOR AIR CONCENTRATIONS.

Statistic	Groundwater (GW > 1,000X Bkgd)	Exterior Soil Gas (SG > 50X Bkgd)	Sub-slab Soil Gas (SS > 50X Bkgd)	Crawl Space (IA > Bkgd)
Min	1.0E-07	5.0E-06	2.5E-05	5.7E-02
5%	3.6E-06	7.6E-05	3.2E-04	1.0E-01
25%	2.3E-05	6.0E-04	1.5E-03	2.2E-01
50%	7.4E-05	3.8E-03	2.7E-03	3.9E-01
75%	2.0E-04	2.7E-02	6.8E-03	6.9E-01
95%	1.2E-03	2.5E-01	2.6E-02	9.0E-01
Max	2.1E-02	1.3E+00	9.4E-01	9.2E-01
Mean	2.8E-04	5.0E-02	9.2E-03	4.6E-01
StdDev	1.0E-03	1.7E-01	5.0E-02	2.8E-01
95UCL	3.4E-04	7.8E-02	1.3E-02	5.3E-01
Count All	774	106	431	41
Count >RL	743	106	411	41
Count <RL	31	0	20	0
No. of sites	24	11	12	4

Note: The applied database screens are groundwater (vapor) concentrations > 1,000X "background," exterior soil gas > 50X "background," sub-slab soil gas > 50X "background," and for crawl space, indoor air concentrations > 1X "background." SOURCE: Table 19 in EPA (2012a).

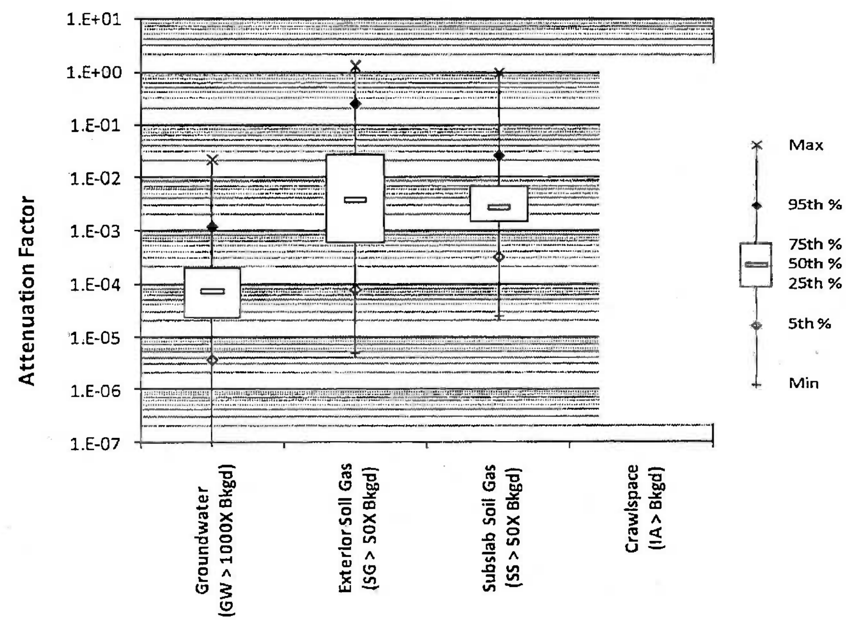


Figure B-1. **Box-and-whisker plots summarizing attenuation factor distributions for groundwater, exterior soil gas, sub-slab soil gas, and crawl space vapor after application of the database screens considered most effective at minimizing the influence of background sources on indoor air concentrations.** SOURCE: Figure 34 in EPA (2012a).

TABLE B 2.
DESCRIPTIVE STATISTICS SUMMARIZING GROUNDWATER ATTENUATION FACTOR DISTRIBUTIONS FOR INDIVIDUAL SITES COMPARED WITH THE COMBINED DATA SET AFTER SOURCE STRENGTH SCREEN (GROUNDWATER VAPOR CONCENTRATIONS > 1,000 TIMES BACKGROUND").

Statistic	GW > 1,000 X Bkgd	Allepo	Alliant	BillingsPCE	CDOT	Davis	Eau Claire	Endicott	Grants	Hamilton-Sundstrand	Harcros/Tri State	Hopewell Precision	Jackson	LAFB	Lockwood	MADEP 1	MADEP 2	Moffet	Mountain View	Rapid City	Redfield	SCM - Cortlandville	Uncasville	Wall	West Side Corp.
Min	1.0E-07	9.1E-06	2.5E-06	1.0E-06	1.8E-06	4.7E-05	3.6E-06	1.9E-05	1.0E-07	9.6E-06	1.2E-06	2.5E-05		2.9E-06	8.6E-07	1.6E-04		1.3E-06	4.8E-07	9.9E-06	1.7E-06	5.9E-05	3.3E-05	1.4E-06	2.1E-06
5%	3.6E-06			1.1E-05	3.4E-06			2.8E-05	9.7E-07	1.2E-05		1.7E-04		4.0E-06	2.9E-06						7.6E-06	5.9E-05		1.7E-05	1.3E-05
25%	2.3E-05			2.1E-05	9.9E-06			2.8E-05	2.7E-06	5.8E-05		2.9E-04		1.7E-05	1.9E-05						2.8E-05	5.9E-05	3.5E-04	2.9E-05	1.5E-05
50%	7.4E-05		3.7E-06	3.9E-05	2.2E-05		2.5E-04	1.7E-04	1.2E-05	1.0E-04	2.5E-04	5.6E-04	4.7E-04	3.4E-05	8.8E-05		4.0E-05	4.0E-06	3.3E-06	3.1E-05	7.3E-05	3.1E-04	4.8E-04	8.2E-05	3.7E-05
75%	2.0E-04			8.9E-05	1.5E-04			7.0E-04	8.7E-05	1.5E-04		1.2E-03		1.4E-04	2.7E-04						1.5E-04	1.7E-03	6.5E-04	3.2E-04	2.7E-04
95%	1.2E-03			6.8E-04	5.4E-04			1.4E-03	2.9E-04	2.9E-04		7.7E-03		6.8E-04	1.3E-03						4.8E-04	4.2E-03		1.4E-03	4.3E-03
Max	2.1E-02	1.4E-05	1.1E-03	8.0E-04	5.4E-04	4.3E-04	1.9E-03	1.5E-03	2.9E-04	5.2E-04	3.7E-03	7.7E-03		2.3E-03	2.4E-03	1.0E-03		1.9E-05	3.3E-05	4.0E-05	1.8E-03	6.6E-03	1.8E-03	1.1E-02	2.1E-02
Mean	2.8E-04		1.1E-04	1.2E-04	1.1E-04	2.4E-04	7.7E-04	4.3E-04	7.5E-05	1.2E-04	7.1E-04	1.2E-03		1.6E-04	2.6E-04	6.0E-04		7.9E-06	9.7E-06	2.7E-05	1.3E-04	1.1E-03	6.0E-04	4.9E-04	1.1E-03
StdDev	1.0E-03		3.4E-04	2.1E-04	1.7E-04		8.1E-04	4.8E-04	1.1E-04	9.8E-05	1.3E-03	1.8E-03		3.6E-04	4.5E-04			9.3E-06	1.4E-05	1.6E-05	1.9E-04	1.6E-03	5.1E-04	1.7E-03	4.0E-03
95UCL	3.4E-04		2.8E-04	1.9E-04	1.8E-04		1.4E-03	5.7E-04	1.2E-04	1.5E-04	1.7E-03	2.0E-03		2.2E-04	3.5E-04			2.4E-05	2.3E-05	5.4E-05	1.5E-04	1.6E-03	9.2E-04	9.2E-04	2.3E-03
Count All	774	2	12	25	17	2	6	32	14	32	7	17	1	93	63	2	1	3	5	3	329	28	9	43	28
Count >RL	743	1	5	25	17	2	6	22	14	32	7	17	1	93	63	2	1	3	5	3	329	21	9	43	22
Count <RL	31	1	7	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	6

SOURCE: Table 13 in EPA (2012a).

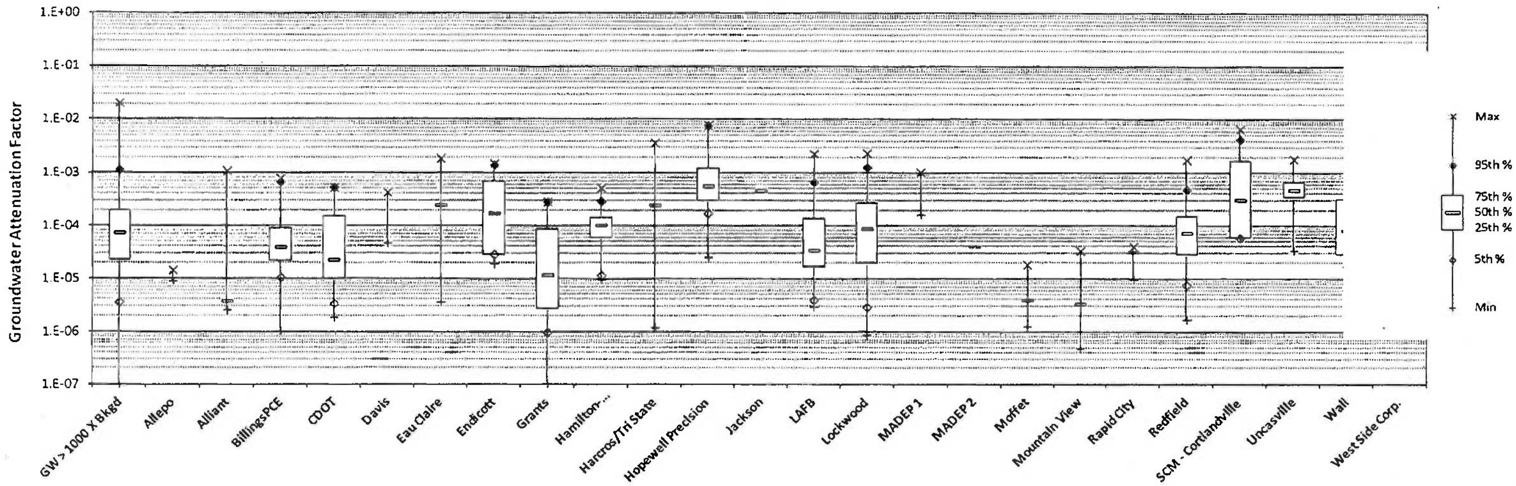


Figure B-2. Box-and-whisker plots summarizing groundwater attenuation factor distributions for individual sites compared with the combined data set after Source Strength Screen (groundwater vapor concentrations > 1,000 times "background"). SOURCE: Figure 28 in EPA (2012a).

TABLE B 3.
DESCRIPTIVE STATISTICS SUMMARIZING GROUNDWATER ATTENUATION FACTOR DISTRIBUTIONS FOR SPECIFIC SOIL TYPES AFTER SOURCE STRENGTH SCREEN.

Statistic	Soil Type Below Foundation		
	Fine	Coarse	V.Coarse
Min	1.0E-07	4.8E-07	2.1E-06
5%	2.3E-06	7.6E-06	1.3E-05
25%	1.9E-05	3.1E-05	2.0E-05
50%	4.6E-05	1.0E-04	1.5E-04
75%	1.4E-04	2.5E-04	6.8E-04
95%	4.5E-04	1.4E-03	4.2E-03
Max	2.4E-03	1.1E-02	2.1E-02
Mean	1.3E-04	3.3E-04	9.7E-04
StdDev	2.4E-04	8.9E-04	3.0E-03
95UCL	1.5E-04	4.1E-04	1.7E-03
Count All	353	369	52
Count >RL	344	359	40
Count <RL	9	10	12
No. of sites	10	15	3

SOURCE: Table 14 in EPA (2012a).

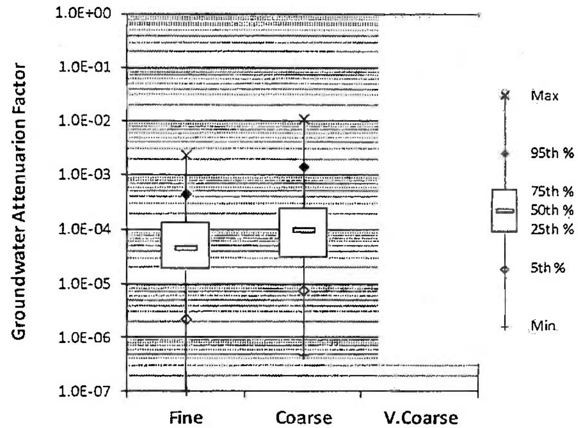


Figure B-3. Box-and-whisker plots summarizing groundwater attenuation factor distributions for specific soil types after Source Strength Screen. SOURCE: Figure 29 in EPA (2012a).

TABLE B 4.
DESCRIPTIVE STATISTICS SUMMARIZING SUB SLAB ATTENUATION FACTOR DISTRIBUTIONS FOR INDIVIDUAL SITES COMPARED WITH THE COMBINED DATA SET AFTER SOURCE STRENGTH SCREEN (SUB SLAB SOIL GAS CONCENTRATIONS > 50 TIMES "BACKGROUND").

Statistic	55 > 50X Bkgd	BillingsPCE	DenverPCEBB	Endicott	Georgetown	Harcros/Tri State	Hopewell Precision	Jackson	LAFB	Orion Park	Raymark	SCM-Cortlandville	West Side Corporation
Min	2.5E-05	2.5E-05	1.1E-03	2.6E-04	1.3E-03	3.8E-04	1.5E-03		3.5E-05	5.0E-04	2.5E-04	3.4E-03	2.0E-04
5%	3.2E-04	9.6E-05		6.9E-04			1.9E-03		1.4E-04		1.2E-03	3.6E-03	
25%	1.5E-03	4.6E-04		1.7E-03			5.0E-03		4.1E-04	1.8E-03	2.0E-03	7.1E-03	5.9E-04
50%	2.7E-03	7.0E-04	6.4E-03	2.6E-03	1.9E-03	4.5E-04	1.0E-02	8.4E-03	1.9E-03	2.8E-03	5.5E-03	1.8E-02	1.5E-03
75%	6.8E-03	1.5E-03		5.0E-03			1.8E-02		5.3E-03	8.8E-03	8.3E-03	4.1E-02	9.7E-03
95%	2.6E-02	2.6E-03		1.1E-02			3.4E-02		3.2E-02		2.1E-02	1.5E-01	
Max	9.4E-01	2.7E-03	4.1E-02	9.4E-01	2.9E-03	2.7E-03	3.4E-02		4.2E-02	3.3E-02	7.9E-02	1.5E-01	3.5E-01
Mean	9.2E-03	9.5E-04	1.7E-02	8.5E-03	2.0E-03	1.0E-03	1.3E-02	8.4E-03	5.0E-03	7.6E-03	7.4E-03	4.1E-02	4.3E-02
StdDev	5.0E-02	7.7E-04	1.9E-02	6.5E-02	8.4E-04	1.1E-03	1.0E-02		9.0E-03	1.1E-02	1.0E-02	5.0E-02	1.2E-01
95UCL	1.3E-02	1.2E-03	3.5E-02	1.6E-02	3.5E-03	2.3E-03	1.7E-02		7.1E-03	1.4E-02	9.2E-03	6.8E-02	1.2E-01
No. of AFs	431	27	5	207	3	4	19	1	52	9	83	12	9
No. of AFs > RL	411	27	5	188	3	4	19	1	52	9	83	12	8
No. of AFs < RL	20	0	0	19	0	0	0	0	0	0	0	0	1

SOURCE: Table 10 in EPA (2012a).

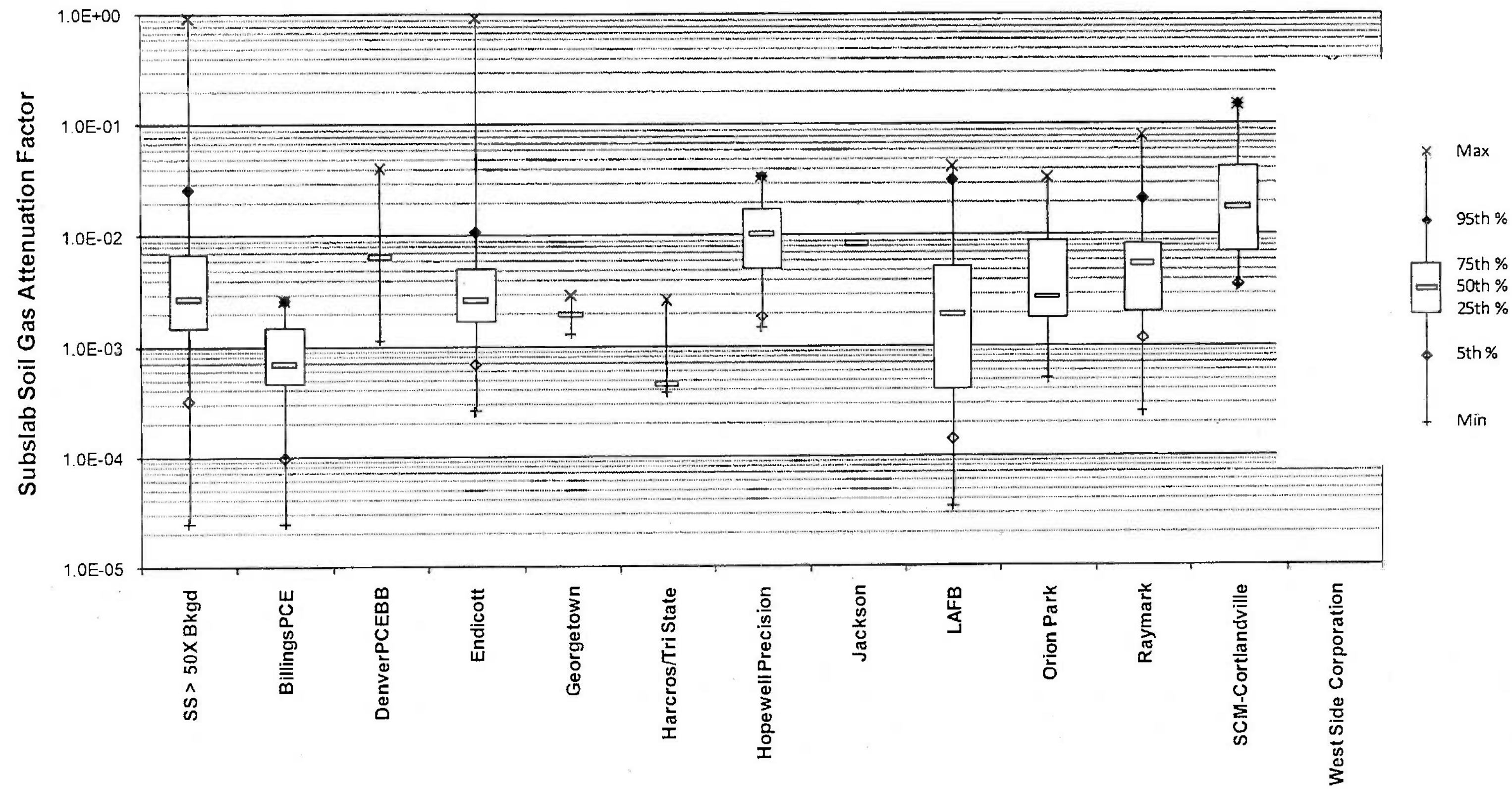


Figure B-4. Box-and-whisker plots summarizing sub-slab soil gas attenuation factor distributions for individual sites after Source Strength Screen (sub-slab soil gas concentrations > 50 times "background"). SOURCE: Figure 25 in EPA (2012a).

TABLE B 5

COMPARISON OF SIZE CHARACTERISTICS FOR RESIDENTIAL AND SOME COMMERCIAL BUILDINGS

Building Parameter and Units	Value and Source for Residential Building	Value and Source for Commercial Buildings, Other Than Warehouses and Enclosed Malls
ACH_{Bldg} (1/hr), 10th percentile	0.18 (EPA 2011, Table 19-1)	0.6 (EPA 2011, Table 19-27)
H_{Bldg} (feet)	8-feet ceiling height (EPA 2011, assumed value)	12-feet ceiling height (EPA 2011, assumed value)

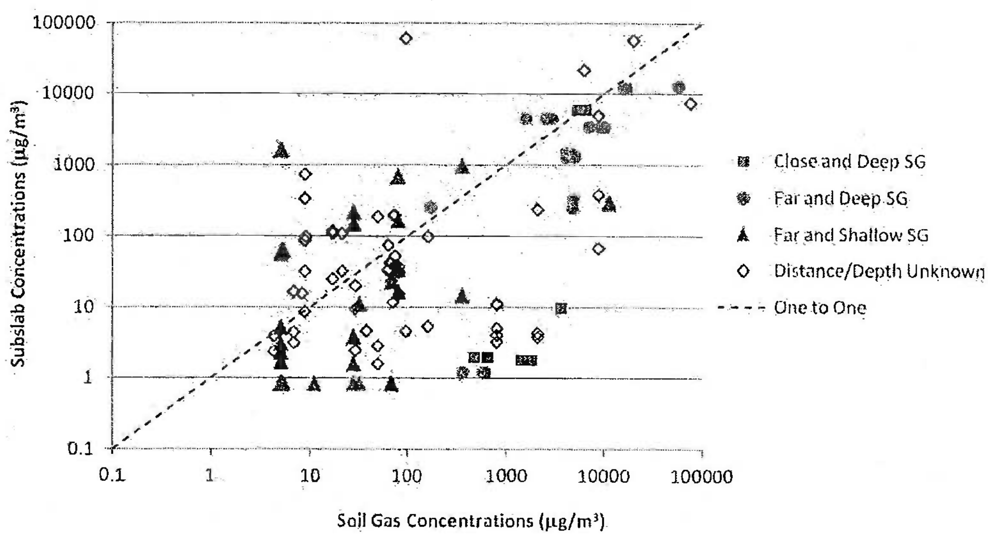


Figure B-5. Exterior soil gas versus sub-slab soil gas concentrations for buildings with both types of data in EPA's vapor intrusion database differentiated qualitatively by horizontal distance to building and depth to the exterior soil gas sample. SOURCE: Figure 6 in EPA (2012a).

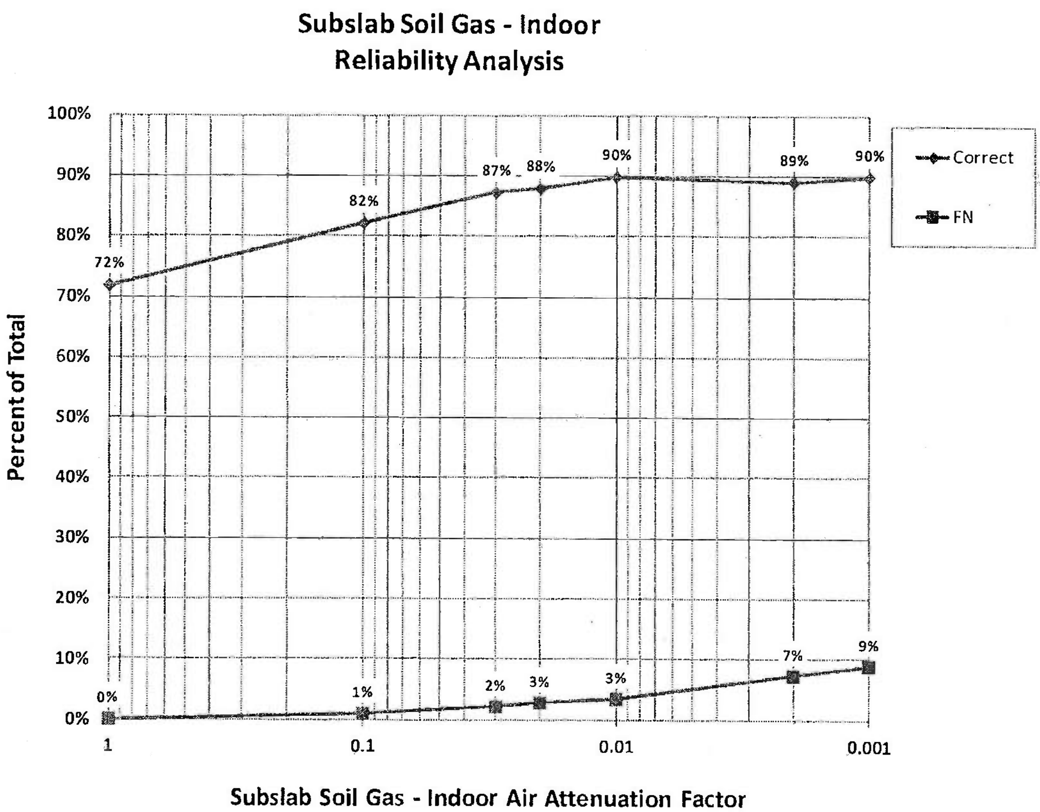


Figure B-6. Reliability Predictions for Alternative Choices of the Sub-slab Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset [tabulated values shown below]

Reliability Analysis: Subslab Soil Gas - Indoor Air

Classification	SS AF = 1	SS AF = 0.1	SS AF = 0.03	SS AF = 0.02	SS AF = 0.01	SS AF = 0.002	SS AF = 0.001
Correct	551	630	669	674	689	683	689
FN	0	7	16	21	26	56	68
Total	767	767	767	767	767	767	767

SS AF	1	0.1	0.03	0.02	0.01	0.002	0.001
Correct	72%	82%	87%	88%	90%	89%	90%
FN	0%	1%	2%	3%	3%	7%	9%

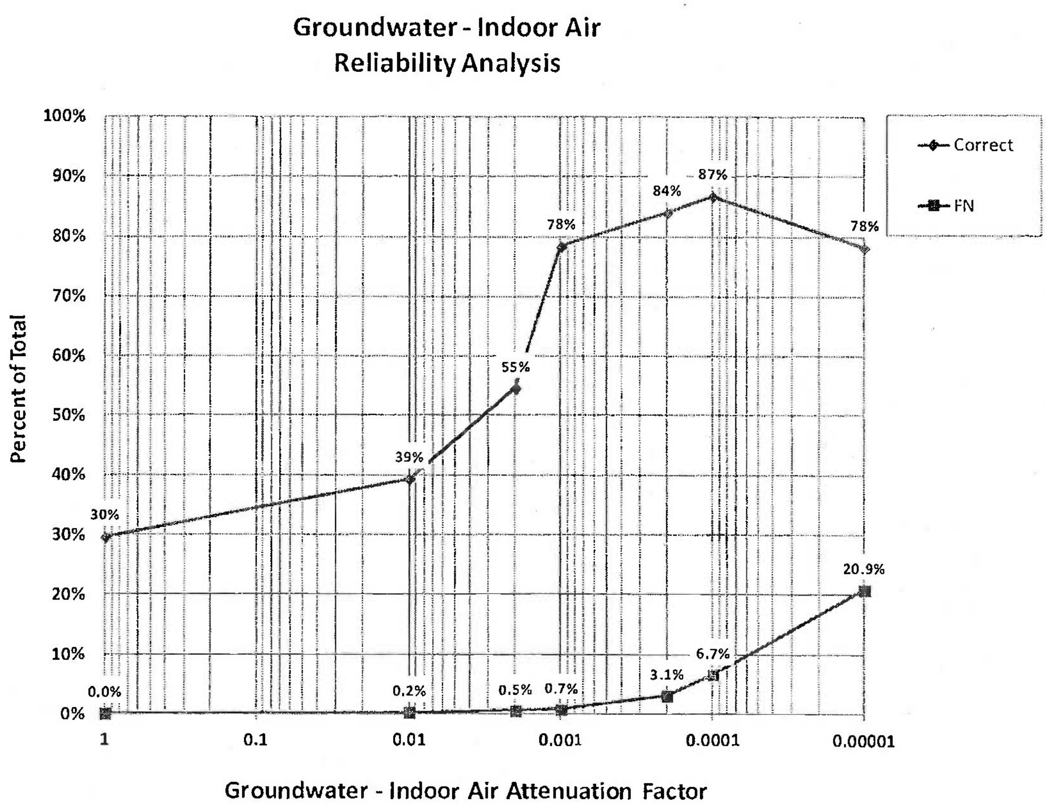


Figure B-7. Reliability Predictions for Alternative Choices of the Groundwater Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset
[tabulated values shown below]

Reliability Analysis: Groundwater -Indoor Air

Classification	GW AF = 1	GW AF = 0.01	GW AF = 0.002	GW AF = 0.001	GW AF = 0.0002	GW AF = 0.0001	GW AF = 0.00001
Correct	240	319	442	635	681	703	634
FN	0	2	4	6	25	54	169
Total	810	810	810	810	810	810	810

GW AF	1	0.01	0.002	0.001	0.0002	0.0001	0.00001
Correct	30%	39%	55%	78%	84%	87%	78%
FN	0.0%	0.2%	0.5%	0.7%	3.1%	6.7%	20.9%

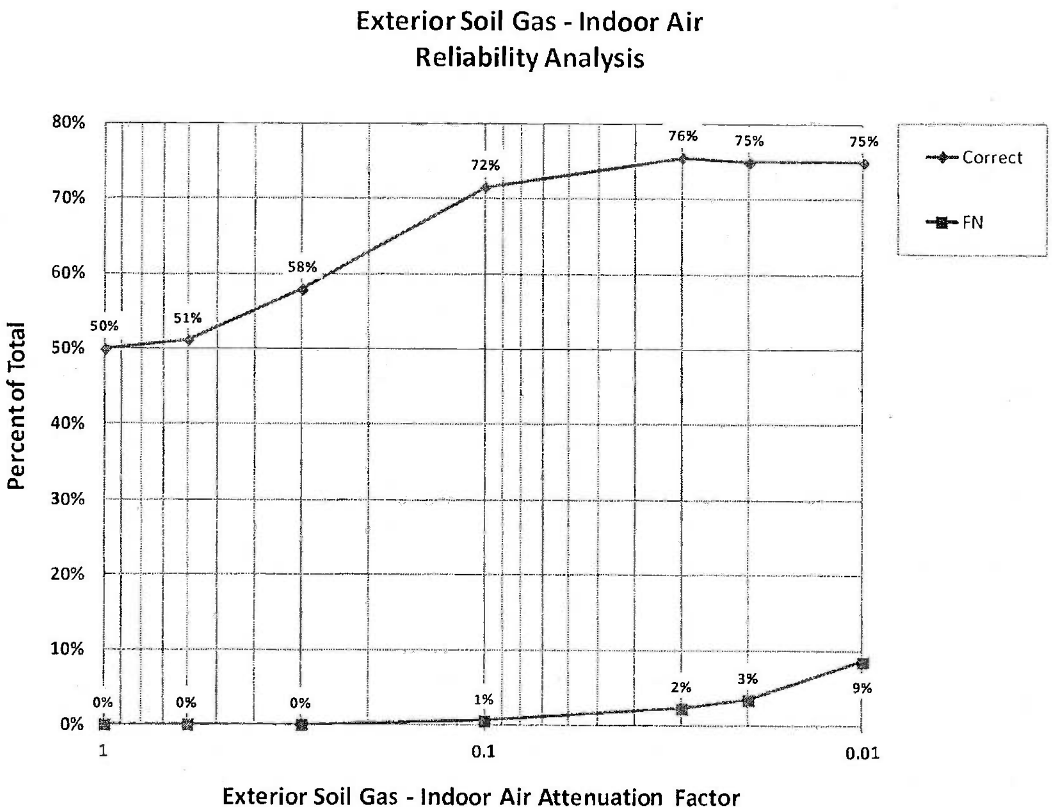


Figure B-8. Reliability Predictions for Alternative Choices of the Exterior Soil Gas Attenuation Factor Based on a Comparison of Paired Data in the Data Consistency Screen Dataset [tabulated values shown below]

Reliability Analysis: Exterior Soil Gas - Indoor Air

Classification	SG AF = 1	SG AF = 0.6	SG AF = 0.3	SG AF = 0.1	SG AF = 0.03	SG AF = 0.02	SG AF = 0.01
Correct	88	90	102	126	133	132	132
FN	0	0	0	1	4	6	15
Total	176	176	176	176	176	176	176

SG AF	1	0.6	0.3	0.1	0.03	0.02	0.01
Correct	50%	51%	58%	72%	76%	75%	75%
FN	0%	0%	0%	1%	2%	3%	9%

APPENDIX C
DATA QUALITY ASSURANCE CONSIDERATIONS

C.1.0 INTRODUCTION

Site-specific investigations of the vapor intrusion pathway will generally require the collection and evaluation of environmental data and possibly the use of modeling. As noted in Exhibit C-1, EPA generally recommends the use of a quality assurance project plan (QAPP) for the collection of primary (and existing or secondary) data. A QAPP is a tool for project managers and planners to document the type and quality of data needed to make environmental decisions and to describe the methods for collecting and assessing the quality and integrity of those data. A QAPP is a plan or roadmap intended to help a project team document how they plan, implement, and evaluate a project. It applies the systematic planning process and the graded approach for collecting environmental data for a specific intended use. EPA standards governing the collection of data are outlined in Exhibit C-1.

Exhibit C-1. EPA Data Standards

CIO 2105 (formerly EPA Order 5360; *Policy and Program Requirements for the Agency-wide Quality System*, May 2000) requires that (1) the organization collecting or using the data has an established Quality System and (2) the project has an approved QAPP.

For clarity, CIO 2105 will be replaced by the following two standards:

- CIO 2106-S-01 is the *Quality Standard for Environmental Data Collection, Production, and Use by EPA Organizations,* also called "Internal Standard" (EPA 2013a); and
- CIO 2106-S-02 is the *Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations*, also called "External Standard" (EPA 2013b).

These standards conform to *EPA Quality Policy*, CIO 2106.0, "Quality Policy" (EPA 2008a), *Procedure for Quality Policy,* CIO 2106-P-01.0, "Quality Procedure" (EPA 2008b), and the American National Standards Institute (ANSI) consensus standard, *Quality Systems for Environmental Data and Technology Programs – Requirements with Guidance for Use* (ANSI/ASQ 2004).

Two guidance documents accompany these standards:

- *EPA Guidance on Quality Management Plans* (EPA 2012b, CIO 2106-G02-QMP), documents the quality system of the organization conducting environmental data collection or using the data for EPA.

- *EPA Guidance on Quality Assurance Project Plans* (EPA 2012a, CIO 2106-G-05) focuses on projects requiring the collection of new data, projects using existing data, and projects involving modeling.

EPA also encourages the use of the *Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP)* (EPA/DoD 2005) as a collaborative approach to satisfy EPA's requirement for a QAPP, especially for Federal Facilities. OSWER Directive 9272.0-17, *Implementation of the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) at Federal Facility Hazardous Waste Sites* (EPA 2005a) and OSWER Directive 9272.0-20 (EPA 2005b) state that QAPPs prepared and approved under the UFP conform to EPA's quality standards and are consistent with EPA Standards CIO 2106-S-0 and CIO 2106-S-02, EPA's Quality Policy (EPA 2008a), and ANSI/ASQ 2004.

C.2.0 RECOMMENDATIONS

This appendix provides two recommendations concerning the key components of QAPP development. These recommendations are not exhaustive, but are included as a starting point as considerations before studying or applying EPA or UFP QAPP guidance.

<u>Recommendation 1</u>: Using the conceptual site model (CSM), develop the project plan and QAPP through a process that involves all key players and share these materials with interested parties in draft form so that potential study weaknesses can be addressed early. The CSM is developed to portray the current understanding of site conditions, the nature and extent of contamination, routes of contaminant transport, potential contaminant pathways, and potentially exposed human populations. Developing the CSM is the first step in EPA's DQO process.

<u>Recommendation 2</u>: Use systematic planning in developing project documents, including the QAPP. Systematic planning is a science-based, common-sense approach designed to ensure that the level of documentation and rigor of effort in planning is commensurate with the intended use of the information and available resources. DQOs are a key component of systematic planning and play a central role in the systematic planning process. DQOs generally are addressed within the QAPP and typically are a critical element in the planning for environmental investigations. *Guidance on Systematic Planning Using the Data Quality Objectives Process (QA/G-4)* (EPA 2006) provides guidance addressing implementation of DQOs and application of systematic planning to generate performance and acceptance criteria for collecting environmental data.

Table C-1 summarizes the steps in the DQO process, the purpose of each step, and provides some examples of how plans could be structured.

TABLE C 1. EXAMPLE OF STEPS IN THE DQO PROCESS

DQO Step	Purpose of the DQO Step	Example Application for Vapor Intrusion
1. State the Problem	Summarize the problem that will require new environmental data (the monitoring hypothesis, the investigation objective(s)) or modeling.	Indoor air in one or more buildings overlying a shallow plume of PCE-contaminated groundwater is (are) to be sampled to determine whether PCE is present. The original PCE release occurred at an industrial site approximately 1,000 feet away from the closest building.
2. Identify the Decision	Identify the decision that requires new data or analysis to address the problem.	The data will be used to support decisions about whether additional indoor air sampling or preemptive vapor intrusion mitigation will be pursued in one or more buildings.
3. Identify the Inputs to the Decision	Identify the information needed to support the decision and specify the inputs that will require new information.	Indoor air sampling data for one or more buildings, in conjunction with information about measured or interpolated concentrations in groundwater near or underneath the building(s).
4. Define the Boundaries of the Study	Specify the spatial and temporal aspects of the environmental media or endpoints that the data must represent to support the decision.	The boundaries of this initial study area extend a prescribed distance outside the lateral extent of the plume. Eventually, the boundaries of a vapor intrusion impact zone will be defined by the extent to which indoor air contamination can be associated with site-related contamination.
5. Develop a Decision Rule	Develop a logical "if...then" statement that defines the conditions that will inform the decision-maker to choose among alternative decisions.	Buildings with detectable concentrations of PCE in indoor air samples will be considered for additional indoor air sampling or preemptive vapor intrusion mitigation.
6. Specify Tolerable Limits on Decision Errors	Specify acceptable limits on decision errors, which are used to establish performance goals for limiting uncertainty in the analysis.	Analytical limits of detection should be less than risk-based screening levels for PCE to ensure that a building's indoor air concentration is not misidentified.
7. Optimize the Design for Obtaining Data	Identify the most resource-effective sampling and analysis design for generating the information needed to satisfy the DQOs.	Time-integrated samples will be collected in basements and in the first above-ground level of each building. The sampling and analysis plan and approach will be documented in a QAPP.

C.3.0 CITATIONS AND REFERENCES

ANSI/ASQ. 2004. *Quality Systems for Environmental Data and Technology Programs – Requirements with Guidance for Use. E4-2004.* http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI/ASQ+E4-2004

U.S. Environmental Protection Agency (EPA). 2000. *Policy and Program Requirements for the Agency-wide Quality System.* EPA Order CIO 2105. May. http://www.epa.gov/irmpoli8/policies/21050.pdf

U.S. Environmental Protection Agency (EPA). 2005a. *Implementation of the Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP) at Federal Facility Hazardous Waste Sites.* OSWER Directive 9272.0-17. June 7. http://www.epa.gov/fedfac/pdf/oswer_qapp_directive.pdf

U.S. Environmental Protection Agency (EPA). 2005b. *Applicability of the Uniform Federal Policy for Quality Assurance project Plans (EPA-505-04-900A). OSWER Directive* 9272.0-20. December 5. http://www.epa.gov/fedfac/pdf/oswer_9272.0_20.pdf

U.S. Environmental Protection Agency (EPA). 2006. *Guidance on Systematic Planning Using the Data Quality Objectives Process (QA/G-4).* EPA/240/B-06/001. February 2006. http://www.epa.gov/quality/qs-docs/g4-final.pdf

U.S. Environmental Protection Agency (EPA). 2008a. *U.S. Environmental Protection Agency Quality Policy.* CIO 2106.0. http://www.epa.gov/irmpoli8/policies/21060.pdf

U.S. Environmental Protection Agency (EPA). 2008b. *U.S. Environmental Protection Agency Procedure for Quality Policy.* CIO 2106-P-01.0. http://www.epa.gov/irmpoli8/policies/21060.pdf

U.S. Environmental Protection Agency (EPA). 2012a. *U.S. Environmental Protection Agency Guidance on Quality Assurance Project Plans.* CIO 2106-G-05 QAPP. January 17. http://www.epa.gov/oeitribalcoordination/2106-G-05%20QAPP%20Final%20Draft%2001-17-12.pdf)

U.S. Environmental Protection Agency (EPA), 2012b. *EPA Draft Final Guidance on Quality Management Plans.* CIO 2106-G02-QMP. January 17. http://www.epa.gov/oeitribalcoordination/2106-G-05%20QAPP%20Final%20Draft%2001-17-12.pdf

U.S. Environmental Protection Agency (EPA). 2013a. *Quality Standard for Environmental Data Collection, Production, and Use by EPA Organizations.* CIO 2106-S-01.

U.S. Environmental Protection Agency (EPA). 2013b. *Draft Final Quality Standard for Environmental Data Collection, Production, and Use by Non-EPA (External) Organizations* (CIO 2106-S-02) "External Standard." February 22. http://www.epa.gov/oeitribalcoordination/External%20Standard%20with%20Annexes.pdf

U.S. Environmental Protection Agency and U.S. Department of Defense (EPA/DoD). 2005. *Uniform Federal Policy for Quality Assurance Project Plans (UFP-QAPP). Part 1: UFP-QAPP Manual.* EPA Publication EPA-505-B-04-900A. DoD Publication DTIC ADA 427785. March. http://www.epa.gov/fedfac/pdf/ufp_qapp_v1_0305.pdf

APPENDIX D
CALCULATING VAPOR SOURCE CONCENTRATION FROM GROUNDWATER SAMPLING DATA

Correcting the Henry's Law Constant for Groundwater Temperature

In the case of groundwater as the vapor source, the subsurface source concentration (C_{sv}) is estimated assuming that the vapor and aqueous phases are in local equilibrium according to Henry's law such that:

$$C_{sv} = H'_{TS} \times C_w \qquad \text{Equation D.1}$$

where:

C_{sv} = vapor concentration at the source of contamination (g/cm^3-v),

H'_{TS} = Henry's law constant at the system (groundwater) temperature (dimensionless), and

C_w = concentration of volatile chemical in groundwater (g/cm^3-w).

The Henry's law constants generally are reported for a temperature of 25 degrees Celsius (°C). **Table D-1** provides these values for the chlorinated hydrocarbons (CHCs) in the vapor intrusion database. Average groundwater temperatures, however, are typically less than 25°C. In such cases, use of the Henry's law constant at 25°C may over-predict the volatility of the contaminant in water.

As described in EPA's *Soil Screening Guidance* (EPA 1996), the dimensionless form of the Henry's law constant at the average groundwater temperature (H'_{gw}) may be estimated using the Clapeyron equation:

$$H'_{gw} = \frac{\exp\left[-\frac{\Delta H_{v,gw}}{R_c} \times \left(\frac{1}{T_{gw}} - \frac{1}{T_R}\right)\right] H_R}{R \times T_{gw}} \qquad \text{Equation D.2}$$

where:

$\Delta H_{v,gw}$ = enthalpy of vaporization of the specific chemical at the groundwater temperature (cal/mol),

T_{gw} = groundwater temperature (°K = °C + 273.15),

T_R = reference temperature for the Henry's law constant (298.15°K),

R_C = gas constant (= 1.9872 cal/mol-°K),

H_R = Henry's law constant for the specific substance at the reference temperature ($atm\text{-}m^3/mol$), and

R = gas constant (= 8.205 E-05 $atm\text{-}m^3/mol\text{-}^{\circ}K$).

The enthalpy of vaporization at the groundwater temperature can be approximated from the enthalpy of vaporization at the normal boiling point, as follows:

$$\Delta H_{v,gw} = \Delta H_{v,b}\left[\frac{\left(1-T_{gw}/T_C\right)}{\left(1-T_B/T_C\right)}\right]^{\eta} \qquad \text{Equation D.3}$$

where:

$\Delta H_{v,gw}$ = enthalpy of vaporization at the groundwater temperature (cal/mol),

$\Delta H_{v,b}$ = enthalpy of vaporization at the normal boiling point (cal/mol),

T_C = critical temperature for specific chemical (°K),

T_B = normal boiling point for specific chemical (°K),

η = exponent (unitless), and

all other symbols are as defined previously. **Table D-1** provides the chemical-specific property values used for temperature corrections to the Henry's law constant. **Table D-2** provides the value of η as a function of the ratio T_B/T_C. If site-specific data are not readily available for the groundwater temperature, then Figure 1 of the EPA fact sheet, *Correcting the Henry's Law Constant for Soil Temperature* (EPA 2001) can be used to generate an estimate.

Citations

EPA (U.S. Environmental Protection Agency). 1996. *Soil Screening Guidance: Technical Background Document.* EPA/540/R-95/128. Office of Solid Waste and Emergency Response. Washington, DC. Available online at: http://www.epa.gov/superfund/health/conmedia/soil/introtbd.htm.

EPA (U.S. Environmental Protection Agency). 2001. *Fact Sheet, Correcting the Henry's Law Constant for Soil Temperature.* Office of Solid Waste and Emergency Response, Washington, DC. Available at http://www.epa.gov/oswer/riskassessment/airmodel/pdf/factsheet.pdf.

EPA (U.S. Environmental Protection Agency). Regions 3, 6, and 9. 2011. *Regional Screening Levels for Chemical Contaminants at Superfund Sites.* November. EPA Region 3, Philadelphia, PA. Available at http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.

Lide, D.R. (Ed.). 1998. *CRC Handbook of Chemistry and Physics, 79th Ed.* Boca Raton, FL. CRC Press.

Mallard, W.G. and P.J. Linstrom (Eds.). 1998. *NIST Chemistry WebBook, NIST Standard Reference Database Number 69.* November. Gaithersburg, MD. National Institute of Standards and Technology. Available at http://webbook.nist.gov/chemistry/.

Table D-1. Chemical-Specific Parameters for Adjusting Henry's Law Coefficients for Groundwater Temperature

Chemical Abstracts Service Registry Number (CASRN)	Alphabetized List of Compounds	Henry's Law Constant @25°C		Henry's Law Constant @25°C[g]	Normal Boiling Point		Critical Temperature		Enthalpy of vaporization at the normal boiling point	
		H_R		H'_R	T_b		T_c		$\Delta H_{v,b}$	
		(atm-m³/mol)	source	(unitless)	(°K)	source	(°K)	source	(cal/mol)	source
56-23-5	Carbon tetrachloride	2.76E-02	a	1.13E+00	3.50E+02	b	5.57E+02	h	7.13E+03	h
75-00-3	Chloroethane (ethyl chloride)	1.11E-02	a	4.54E-01	2.85E+02	b	4.60E+02	f	5.88E+03	f
67-66-3	Chloroform	3.67E-03	a	1.50E-01	3.34E+02	b	5.36E+02	h	6.99E+03	h
75-34-3	Dichloroethane,1,1-	5.62E-03	a	2.30E-01	3.30E+02	b	5.23E+02	h	6.90E+03	h
75-35-4	Dichloroethene, 1,1-	2.61E-02	a	1.07E+00	3.05E+02	b	5.76E+02	h	6.25E+03	h
156-59-2	Dichloroethene,cis-1,2-	4.08E-03	a	1.67E-01	3.28E+02	b	5.44E+02	h	7.19E+03	h
156-60-5	Dichloroethene,trans-1,2-	4.08E-03	a	1.67E-01	3.28E+02	b	5.17E+02	h	6.72E+03	h
75-09-2	Methylene chloride	3.25E-03	a	1.33E-01	3.13E+02	b	5.10E+02	h	6.71E+03	h
127-18-4	Tetrachloroethene	1.77E-02	a	7.23E-01	3.94E+02	b	6.20E+02	h	8.29E+03	h
76-13-1	Trichloro-1,2,2-trifluoroethane,1,1,2-	5.26E-01	a	2.15E+01	3.21E+02	b	4.87E+02	f	6.46E+03	f
71-55-6	Trichloroethane, 1,1,1-	1.72E-02	a	7.03E-01	3.47E+02	b	5.45E+02	h	7.14E+03	h
79-01-6	Trichloroethene	9.85E-03	a	4.03E-01	3.60E+02	b	5.44E+02	h	7.51E+03	h
75-01-4	Vinyl chloride (chloroethene)	2.78E-02	a	1.14E+00	2.60E+02	b	4.32E+02	h	5.25E+03	h

Sources and Footnotes:

a Based on values reported in the U.S. EPA Regional Screening Tables. November 2011. Available online at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/xls/params_sl_table_run_NOV2011.xls

b Experimental values. EPA 2009. *Estimation Programs Interface Suite™ for Microsoft® Windows, v 4.00.* U.S EPA, Washington, DC, USA. Available online at: http://www.epa.gov/opptintr/exposure/pubs/episuite.htm

f *CRC Handbook of Chemistry and Physics, 76th Edition*

h EPA (2001). FACT SHEET *Correcting the Henry's Law Constant for Soil Temperature.* Attachment.

g National Institute of Standards and Technology (NIST). *Chemistry WebBook.* Available online at http://webbook.nist.gov/chemistry/

Table D-2. Values of Exponent η as a Function of T_B/T_C

Chemical-specific ratio T_B/T_C	H
< 0.57	0.30
0.57 - 0.71	0.74 (T_B/T_C) - 0.116
> 0.71	0.41

EXHIBIT H

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105

July 30, 2013

Mr. Aaron Greenspan
884 College Avenue
Palo Alto, CA 94306
aarong@thinkcomputer.com

Certified Mail No. 7006 0810 0003 9311 6236
Return Receipt Requested

Re: Hewlett-Packard Superfund Site, 620-640 Page Mill Road, Palo Alto, CA

Dear Mr. Greenspan:

Thank you for your inquiry of June 26, 2013 to the Regional Administrator regarding the ongoing investigation and cleanup at the Hewlett-Packard Superfund Site (the Site) located at 620-640 Page Mill Road in Palo Alto. The U.S. Environmental Protection Agency (EPA), the San Francisco Regional Water Quality Board (Regional Water Board), and the City of Palo Alto have been working in partnership for over 15 years to ensure that the community is protected from all contamination related to the Site.

The area impacted by the Site has been extremely well defined, with the Site data reviewed by and concurred upon by numerous technical experts. All of the indoor air of residences that could be impacted by the Site has been tested and found to be safe.

EPA would like to assure you that the drinking water, neighborhood soils, and indoor air in the community is safe from the contamination in the groundwater, which will continue to undergo remediation until the Site cleanup levels are achieved.

We hope that this letter satisfies your concerns and concludes the many months of correspondence and conference calls between yourself, EPA and its agency partners. Some additional information in response to your specific inquiries is provided below.

- Residents are protected from the contamination in the groundwater because their water supply does not come from the underground aquifer. Rather, it comes through the City of Palo Alto's water distribution system, which brings in clean water from the Sierras and is regularly tested to ensure its high quality. A groundwater treatment system has been in place since 1995 to address the contaminated groundwater, with ongoing monitoring and analysis. Any surface soil contamination associated with historic Site activities was remediated in the 1990s. Thus, the soccer field you discuss in an April 3, 2013 e-mail to the Water Board is safe to access.

- The indoor air of residences on and around the Site is safe from any vapor intrusion associated with the underground plume. Extensive indoor air testing of residences directly over the plume has shown this to be the case. EPA does not plan to offer any additional indoor air testing to residents in other areas of the neighborhood, given that no indoor air contamination was found in the households directly overlying the areas of highest contamination. Related to the residents of College Avenue, based on the data that has been collected EPA does not believe that College Avenue overlies a contaminated zone.

- In the April 3, 2013 e-mail to the Regional Water Board, you also expressed concern over the number of groundwater monitoring wells in the College Terrace residential area bordering the Site to the northwest. EPA and the Regional Water Board, together with numerous technical experts, consider the Site to be extremely well characterized. However, being responsive to your concerns, the Regional Water Board investigated the monitoring well installation and subsurface hydrogeology and agreed to add one additional monitoring well about half-way between existing wells V8-6 and V-10 that currently define the northwest plume boundary passing along California Avenue.

- Related to your question on monitoring well data for Google buildings, please visit the EPA website for all available maps and technical documents. For monitoring wells in the vicinity of the Google buildings (associated with EPA's MEW Superfund Site), please visit EPA's MEW website and visit the "Technical Documents" section for the document entitled "2012 Annual Progress Report for MEW Regional Groundwater Remediation Program 04/15/13" and open Appendix C – contour maps of all MEW wells: www.epa.gov/region9/mew

- For the Regional Water Board sites, please access site documents through their GeoTracker website: https://geotracker.waterboards.ca.gov/regulators/login.asp

- With respect to community outreach, EPA takes seriously its commitment to informing the community about Site activities. In conjunction with EPA's and the Regional Water Board's cleanup efforts at this Site and the other South Bay projects, community outreach may include in-person visits to residences and businesses within the area of concern, meetings, mailings, websites, and public notices as warranted, to ensure that affected community members are informed about cleanup activities and have an opportunity to express their concerns directly to agency officials.

- Lastly, in your June 23, 2013 e-mail you expressed skepticism toward the integrity of the data collected at the Site. Please be assured that EPA and the Regional Water Board place the highest importance on the integrity and reliability of data collected at Superfund Sites, and all responsible parties are required to comply with rigorous Quality Assurance standards. In the State of California, the submitting parties are licensed by the State to practice engineering or geology. State regulations governing their practice strongly encourage the submittal of documents that are true and correct to the best of one's knowledge because not doing so puts licenses at risk.

We hope that this letter satisfies your concerns and concludes the many months of correspondence and conference calls between yourself, EPA and its agency partners. The contacts for the Site are Melanie Morash, EPA Remedial Project Manager at (415) 972-3050 or morash.melanie@epa.gov, Vicki Rosen, EPA Community Involvement Coordinator at (415) 972-3244 or rosen.vicki@epa.gov, and Roger Papler, Regional Water Board Engineering Geologist at (510) 622-2435 or roger.papler@waterboards.ca.gov.

Sincerely,

Kathleen Salyer

Kathleen Salyer, Assistant Director
Site Cleanup Branch, Superfund Division

Cc:

John Wolfenden, Section Leader, San Francisco Bay Regional Water Quality Board
Roger Papler, Engineering Geologist, San Francisco Bay Regional Water Quality Board
Jason Nortz, Senior Planner, City of Palo Alto
Sue Dremann, Palo Alto Weekly
John Gabaix
Fred Balin