Evaluating Vapor Intrusion Pathways at Hazardous Waste Sites

Introduction

Volatile organic chemicals (VOCs), such as solvents, are among the most common contaminants released into the environment from hazardous waste sites. In addition to contaminating groundwater and soils, these chemicals may off-gas from soils and groundwater and seep into the air of homes and commercial buildings. Asphyxiating and flammable gases can also behave similarly to VOCs, in addition to some non-organic volatiles, such as mercury, radon, carbon dioxide, hydrogen sulfide and sulfur dioxide. This movement of volatile chemicals and gases from soil and groundwater into indoor air is known as the vapor intrusion pathway.

Designed for environmental health professionals, this document focuses on how to evaluate the public health implications of vapor intrusion. This document is being issued as a technical supplement to the January 2005 Public Health Assessment Guidance Manual (PHAGM) prepared by the Agency for Toxic Substances and Disease Registry (ATSDR). As a supplement, the discussion will not repeat the basic concepts and processes of the public health assessments found in the PHAGM (http://www.atsdr.cdc.gov/HAC/PHAManual/index.html) (1).

Although sometimes associated with VOC contaminated groundwater, landfill gas will not specifically be addressed in this document. For a discussion of landfill gas, readers should review the ATSDR Landfill Gas Primer at http://www.atsdr.cdc.gov/HAC/landfill/html/intro.html (2).

Since the 1980s, vapor intrusion has been the subject of increasing research and scientific discussion. However, the research and discussion did not yield a national consensus on methods of evaluation until 2002. Problems in consistent characterization of vapor intrusion at hazardous waste sites led the U.S. Environmental Protection Agency (EPA) to issue draft guidelines in 2002 (http://www.epa.gov/epaoswer/hazwaste/ca/eis/vapor.htm) (3). Many state health and environmental agencies have also issued their own guidelines for evaluating vapor intrusion. The majority of the state guidelines appear to follow the approach proposed by EPA with the addition of state-specific screening levels for contaminants. Many states are developing vapor intrusion guidance, and a frequently updated list of state guidance documents is available at http://www.envirogroup.com/links.php (4). Recently, a comprehensive guidance document on vapor intrusion was prepared by scientists and engineers from 19 state and 4 federal agencies and members of the regulated community under the auspices of the Interstate Technology and Regulatory Council (ITRC; http://www.itrcweb.org) (5).

This document does not attempt to duplicate the in-depth information provided by of EPA, state agencies, or the ITRC. Instead, the guidance documents prepared by other agencies are used as references and springboards for discussion of public health practices when evaluating vapor intrusion. In particular, the ITRC document, *Vapor Intrusion: A Practical Guideline* (http://www.itrcweb.org/Documents/VI-1.pdf) (5) is recommended for use by health assessors as a reference for vapor intrusion issues. The ITRC vapor intrusion guidance is intended to aid regulatory agencies in their investigation and remediation of vapor intrusion problems. The ITRC guidance also includes a discussion (Appendix H) of how screening levels are created and used by state agencies.

As a document intended for internet publication, links to appropriate references and source documents, such as the ITRC guidance noted above, will be provided throughout this document. Readers are forewarned that these links may not be updated. If a link fails, readers are encouraged to use appropriate search programs to find the updated web address, assuming the document is still available on the internet.

ATSDR recognizes that many environmental and health organizations have developed excellent resources to evaluate vapor intrusion fate and transport. ATSDR uses the information gained from vapor intrusion fate and transport analyses to determine if exposure to a contaminant poses a health hazard. This evaluation requires a tool that provides dependable information for making health conclusions. ATSDR finds that some guidances serve ATSDR's mission better for some site-specific criteria. Therefore, this document was developed to assist health assessors with choosing from the many available policies for their site-specific needs.

What are the health risks from the vapor intrusion pathway?

As discussed in the Wisconsin Department of Health guidance on chemical vapor intrusion and residential air (http://dhfs.wisconsin.gov/eh/Air/pdf/VI_guide.pdf) (6), vapor intrusion into indoor air can be of public health concern because volatile organic compounds (VOCs) in air are readily absorbed by the lungs. If groundwater is contaminated with VOCs, inhalation of VOCs from groundwater may pose a greater hazard than drinking the water. Intrusion of contaminated soil gases into indoor air may lead to the following health and safety issues: fire, explosion and acute, intermediate and chronic health effects. Asphyxiation is a possible but less likely problem.

Fire and explosion

Vapors from leaking buried fuel tanks and fuel pipelines may enter nearby occupied buildings; creating the potential for fire and explosion if they accumulate to sufficient concentration in a confined space such as a basement room or a utility room. If carried by shallow groundwater, the fuels tend to stay at the top of the saturated zone in relatively high concentrations and thereby increase the potential for entry into any building basement or a buried utility system (i.e. storm sewers) that might intercept a high water table.

Acute health effects

Acute (short term) health effects from VOCs include headaches, nausea, eye and respiratory irritation. Such health effects are sometimes associated with petroleum-based air contaminants, such as diesel fuel and heating oils. Benzene is a chemical associated with fuel vapors that may be acutely irritating at low levels (http://www.epa.gov/ttn/atw/hlthef/benzene.html) (7). People with pre-existing respiratory problems, such as asthma, chronic obstructive pulmonary disease and children, may be affected more than healthy adults.

Intermediate health effects

Health effects from intermediate duration exposures (14 days to 364 days) for VOCs can include liver, neurological and reproductive effects. Few studies involving human exposures have been performed for intermediate duration exposures. However, effect levels observed in animal studies are modified by safety factors to give conservative values for screening. If these screening values are exceeded, ATSDR's Toxicological Profiles (http://www.atsdr.cdc.gov/toxpro2.html) (8) and current toxicological literature should be consulted to evaluate potential health effects. Chapter 8 of ATSDR's PHAGM provides guidance on the in-depth analysis of health effects.

Chronic health effects

Health effects associated with long-term inhalation of air contaminants include both cancer and non-cancer health effects. The non-cancer health effects most frequently associated with inhalation of relatively high levels of chlorinated VOCs are damage to the liver, kidneys, and nervous system.

Cancer health effects

Many VOCs are classified as known human carcinogens or reasonably anticipated to be a human carcinogen. For many carcinogenic chemicals, there is no clear threshold below which there is no increased risk of cancer. Therefore, even though most indoor air concentrations of chemicals from vapor intrusion are not likely to result in observable increases in cancer rates for exposed populations, prudent public health practice is to minimize exposures to cancer causing chemicals.

Asphyxiation

Infiltrating vapors, particularly heavier than air gases such as carbon dioxide, can displace and reduce the oxygen in occupied spaces to below life sustaining levels. Though low indoor air oxygen levels have resulted from infiltration of landfill and petroleum derived gases, the asphyxiation hazard has not been associated with infiltration of chlorinated VOCs.

When should a vapor intrusion pathway be evaluated?

There are two basic criteria for determining if it is necessary to evaluate vapor intrusion at a hazardous waste site. First, volatile contaminants must be present in the subsurface, and second, buildings must be laterally and vertically close enough to the subsurface contaminants for concentrations above health concern levels to reach indoor breathing zones. The 2005 California Department of Toxic Substances Control guidance at http://www.dtsc.ca.gov/loader.cfm?url=/commonspot/security/getfile.cfm&pageid=11492 (9) discusses these criteria in more detail. Future use of contaminated areas should also be considered.

Why is it so difficult to assess the public health hazard posed by the vapor intrusion pathway?

Vapor intrusion is a complex problem with multiple variables (factors) and often too few measurements. Determining the environmental health hazards from air contaminants in homes and commercial buildings is often difficult because of the dynamic nature of the media and the need to assess the entire period of time people are inhaling the contaminants.

The concentrations of contaminants entering the indoor air from subsurface are dependent upon site and building specific factors such as building construction, number and spacing of cracks and holes in foundation, and the impact of the heating and air conditioning system on increasing or decreasing flow from the subsurface. Soil type and moisture between the building and source area, time of year, and tidal effects also affect vapor migration to indoor air.

Health assessors are seldom provided with adequate information to discriminate the contribution of vapor intrusion contaminants from other sources of indoor air contamination. Common sources of indoor air contaminants include household products, stored fuels, furniture, flooring products, dry cleaned clothing, and outdoor air contaminants. In addition, indoor air is a dynamic media with frequent changes in air flow and air composition. Concentrations of air contaminants may change significantly over the course of a single day as a result of air exchange with outside air or the introduction of a temporary source of contaminants, such as furniture polish or paint.

What is the best approach for a public health evaluation of the vapor intrusion pathway?

Many experienced investigators, including those who produced the ITRC guidance, believe that a multiple lines of evidence approach provides the best means of evaluating the vapor intrusion pathway. Such an approach is used in the public evaluation steps described in the following section.

Public Health Evaluation

The EPA and ITRC guidance documents and most of the state guidance documents establish a multiple lines of evidence approach to evaluating vapor intrusion. For example, the ITRC guidance has a 13 step approach that includes gathering information on multiple lines of evidence such as, subsurface samples, preferential pathways, geology, soils, and building conditions. This document recommends a very similar approach with several steps that parallel the ITRC guidance. The major parts of a public health evaluation are Pathway Analysis, Exposure Evaluation, Health Implications, and Conclusions and Recommendations.

Outline of Evaluation Process (detailed explanation of evaluation steps starting with Step 4 follows outline)

I. Pathway Analysis
   1. Are there subsurface volatile chemicals reported or suspected?
   2. Are there occupied buildings within 100 feet laterally or vertically of volatile subsurface contaminants? If the answer is no, are preferential pathways (such as mining shafts, utility conduits, fractures or karst features) present that may result in transport over unusually long distances to occupied buildings?
   3. Are reported concentrations of volatile subsurface contaminants near the buildings documented to be, or plausibly above applicable screening levels? Appendix H of the ITRC guide discusses the development and application of screening levels

If the answer to any of the 3 questions above is no, then human exposure to harmful levels of contaminants from vapor intrusion is unlikely. If the answer to all three questions is yes, continue the evaluation process with the following steps.

   3. Begin developing and improving Conceptual Site Model (described below).
   4. Search for evidence of any urgent public health hazards such as fire and explosion hazards or potential exposures to free product.
   5. Evaluate distance between contaminants and occupied buildings.
   6. Evaluate environmental information, environmental concentrations of contaminants in nearby soil, groundwater, and soil gas, and potential background sources.
   7. Evaluate building construction characteristics, such as basements, sumps, drainage, ventilation systems, relative elevation, and other critical features.
   8. Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings (i.e. buried utility lines, known shallow fracture flow zones, or solution channels).

II. Exposure Evaluation (Dose Estimation)
   9. Are there valid indoor air measurements to use for dose calculation?
   10. If there are no valid indoor air measurements, are there subslab soil gas measurements and other site specific information that can be used to estimate

indoor air concentrations using reasonable but conservative attenuation factors from observations (Dawson, Hers, & Truesdale, 2007) (17) or from appropriate models, such as the Johnson and Ettinger model? (http://www.epa.gov/oswer/riskassessment/airmodel/pdf/2004_0222_3phase_users_guide.pdf). (18)

11. Request further site specific information and measurements if the answer to the items 10 & 11 above is negative.

III. Public Health Implications

12. If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

IV. Public Health Conclusions, Recommendations, and Public Health Action Plan

14. Follow the Public Health Assessment Guidance Manual

Detailed Explanation of Evaluation Steps starting with Step 4.

Step 4) Conceptual Site Model:

Develop and improve a conceptual model of the site and the pathway as you gather, review, and evaluate site specific information. Depending on the need for detailed analyses and reporting, the conceptual site model (CSM) may only be a mental visualization or may be a written or graphic description of the site and the vapor intrusion pathway.

As discussed in the New Jersey Department of Environmental Protection Vapor Intrusion Guidance (http://www.nj.gov/dep/srp/guidance/vaporintrusion/) (10), the basic components of a CSM are: known or suspected contaminant sources, contaminant migration pathways, potential human receptors, and the exposure routes by which these receptors may come in contact with contaminants on a site specific basis.

Sometimes the source of the VOCs reported in private and monitoring groundwater wells is not known or multiple sources are suspected rather than a single source. Even without a specific source, a CSM can still be constructed that provides a visualization of contaminant movement from groundwater toward indoor air.

Spatial information, both vertical and horizontal, such as maps, aerial photography, borehole logs, and regional or local stratigraphy, is very useful for formulating a CSM. For sites involving several buildings spread over more than a city block area, geographic information systems (GIS) provide extremely useful analytical and visualization tools for CSMs and pathway analyses.

In developing the CSM, pay particular attention to the lateral and vertical distances between sample locations of contaminants and the locations of occupied buildings and subsurface work areas (i.e. buried utilities with man-hole access). For example, determine the lateral and vertical distance from a monitoring well with reported concentrations of a VOC and the basement of a nearby residence. For additional information on CSM, health assessors are referred to section 2.1 (page12) of the ITRC guidance titled Developing a Conceptual Site Model.

Step 5) Evaluate Presence of Urgent Public Health Hazards:

When reviewing information on the site, first check for any urgent public health hazards such as fire, explosion, oxygen depletion or the presence of free product. For example, ATSDR found flammable levels of methane and Threshold Limit Value (TLV) levels of hydrogen sulfide while investigating indoor air impacted by groundwater at Cady Road, Ohio (http://www.atsdr.cdc.gov/NEWS/cadyroad_pr_082902.html) (11). If residents or building occupants report unexplainable (no known indoor sources such as fuel tanks or leaking fuel lines), persistent and pervasive fuel odor within the home or building, local fire officials should be contacted to check for possible flammable or explosive conditions. Also local fire officials should be contacted to check oxygen levels in homes or buildings if occupants voice combined complaints about headaches or dizziness and problems such as pilot lights going out. Seeping carbon dioxide or other gases might be replacing the oxygen in the some portion of the building. The National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards lists safety hazards associated with specific chemicals from exposures in an occupational setting (http://www.cdc.gov/niosh/npg/) (12). This topic is also discussed in section 2.3 (page 15) of the ITRC guidance titled Step 1: Does the Site Represent an Acute Exposure Concern?

Step 6) Evaluate Subsurface Environment:

Evaluate the distance between subsurface sources of VOCs (e.g., contaminated groundwater and soil gas) and occupied buildings. According to EPA and state guidance documents, buildings 100 feet beyond the edge of groundwater or soil-gas with concentrations of contaminants above applicable screening levels are less likely to be affected with harmful levels of contaminated gases entering by vapor intrusion than buildings within 100 feet of screening levels. A vertical distance of 100 feet between bottom floor of a building and the top of a contaminated groundwater zone is also often considered an adequate buffer. Both distances assume no preferential pathways are present and other factors such as fluctuations in groundwater levels are minimal. For further discussion of distance between source and buildings, health assessors should review section 2.6 (page 16) of the ITRC guidance titled Step 4: Are Buildings Located in Close Proximity to Volatile Chemicals in Soil, Soil Gas, or Groundwater?

Step 7) Evaluate Environmental Information:

Evaluate the reported contaminant concentrations in groundwater, soil gas and indoor air and the sample locations. As with all environmental health issues (see PHAGM), evaluate the applicability of the sampling and analytical methodology before using the reported results for further public health evaluation. Review Chapter 2 (Investigation of the Soil Vapor Intrusion Pathway) and Chapter 3 (Data Evaluation and Recommendations for Action) from the New York State Department of Health guidance document for more detailed information. (http://www.health.state.ny.us/nysdoh/gas/svi_guidance/docs/svi_main.pdf) (13).

Please note that the presence of indoor air contaminants does not always indicate a completed pathway from the subsurface to indoor air. Always evaluate the presence and concentrations of indoor air contaminants in relation to all sources of contaminants, including the range of background concentrations found in surveys of indoor air contaminants. The New York State Department of Health guidance provides several tables of background concentrations for indoor air contaminants in Appendix C.

Evaluating the applicability of background data to individual sites is recommended on a site-by-site basis. If background sources are present, the EPA Introduction to Indoor Air Quality website (http://www.epa.gov/iaq/ia-intro.html)(15) can be consulted for general information about indoor air pollutants and improving indoor air quality. Data evaluation and background concentrations are discussed in Section 2.4 (page 15) and Section 3.5.4 (page 28) of the ITRC guidance. The Minnesota Department of Health also provides a useful guidance entitled Indoor Air Sampling at VOC Contaminated Sites: Introduction, Methods, and Interpretation of Results at the following website: http://www.health.state.mn.us/divs/eh/hazardous/topics/iasampling0106.pdf (14).

Step 8) Evaluate Building Construction:

Evaluate building construction characteristics, such as foundation type (e.g., basement, slab, crawl-space), foundation condition (e.g., cracks or other openings in basement floors and walls; blocked crawlspace vents), sumps, ventilation systems, drainage, relative elevation, and other critical features. Some construction (post and beam) is largely variable with respect to retarding vapor intrusion. Tightly sealed buildings commonly found in cold climates are more prone to vapor intrusion than houses with vented crawl spaces found in warmer regions. For more information please see the building features discussion on page 2 of the Wisconsin Department of Health guidance at the following website: http://www.dhfs.wisconsin.gov/eh/Air/pdf/VI_guide.pdf. Also, the ITRC guidance contains (Appendix G) the building checklist developed by the New York Department of Health.

Step 9) Preferential Pathways:

Check for any preferential transport pathways from contaminated soil or groundwater toward occupied buildings. Drains, trenches, and buried utility corridors (such as tunnels and pipelines) can act as conduits for gas movement. The natural geology often provides underground pathways, such as fractured rock, porous soil, and buried stream channels, where the gas can migrate. Fluctuations in groundwater levels from flooding or tidal influence may hydraulically flush soil gases to the surface. During the winter time, frozen soils may impede VOCs from escaping from open ground surfaces, thereby increasing the migration of VOCs through unfrozen soil under buildings.

Step 10) Are there valid indoor air measurements to use for dose calculation?

Health Assessors should review the indoor air sampling plan and QA/QC plan to determine if the analytical results are adequate for making public health decisions. The sampling plans can be compared with the recommendations for indoor air sampling in the New York State Health Department guidance for indoor air (http://www.health.state.ny.us/nysdoh/indoor/docs/guidance.pdf) and the New York State Health Department guidance for vapor intrusion (http://www.health.state.ny.us/environmental/investigations/soil_gas/svi_guidance/docs/svi_main.pdf). As noted in the NYSDOH guidance, the health assessor should check on the analytical methods used to determine validity and compatibility with EPA analytical methods.

As a reminder, the indoor air samples cannot distinguish whether the source is from vapor intrusion, ambient air, or transient sources such as commercially dry cleaned clothing stored in a hall closet. Therefore the indoor air results should be compared with ambient air samples and soil gas samples (particularly subslab soil gas samples) taken at the same location and time to evaluate the potential for these media to be the source of indoor air contamination. If possible, information should include more than a single point in time sampling. Low confidence is generally attributed to decisions based on one sampling event, unless there is clear evidence that this will result in a health protective decision. Indoor air monitoring that reflects seasonal variations for the site should provide a better basis for an exposure estimate. The California guidance recommends at least a late summer/early fall sample in addition to a late winter/early spring sample. Page D-22 of the ITRC guide also discusses indoor air sample locations and frequency.

Step 11) What if no valid indoor air measurements are available?

If no valid indoor air measurements are available, determine if there is sufficient site specific information (such as subslab soil gas samples, or crawlspace air samples) to estimate indoor air measurements. When using results from subslab gas samples, crawlspace air samples, or groundwater samples, reasonable but conservative attenuation factors should be used in estimating indoor air concentrations. The ITRC guidance document provides more information on using subslab gas samples, on pages 24 and 39 and more information on attenuation factors on pages H-2, H-3, H-9 and H-10. A recent compilation by EPA of measured attenuation factors from groundwater and subslab to indoor air reported a 95th percentile attenuation factor of about 0.02 for subslab vapor to indoor air (Dawson, Hers, & Truesdale 2007) (17). This database is expected to become publicly available in the near future for review of the information by all interested parties.

When no subslab gas, soil gas or crawlspace air measurements are available, an environmental transport model, such as the Johnson and Ettinger vapor intrusion model, can be used with conservative assumptions to estimate indoor air concentrations of VOCs moving from groundwater through the soil column and into an occupied building. However, even the best model can lead to erroneous estimates if input parameters do not correctly characterize site specific conditions, such as depth to groundwater, soil type, soil moisture, and structure characteristics, as well as building features such as sump pumps, earthen floors, fieldstone walls, crawlspaces, etc. Please review the DHAC guidance on use of fate and transport models at http://intranet.cdc.gov/nceh-atsdr/dhac/hac_modeling.pdf. Also carefully review the guidance provided by USEPA (http://www.epa.gov/athens/publications/reports/Weaver600R05106ReviewRecentResearch.pdf) before using any model to estimate indoor air concentrations.

Cases where groundwater monitoring results were below detection limits have been found to exhibit elevated soil gas contaminant levels. Consequently, groundwater results alone may not accurately predict susceptibility of buildings to the vapor intrusion pathway. Field verification sampling is strongly encouraged to confirm model results, particularly when the model suggests the site poses no risk.

Also consider whether collecting additional environmental measurements might be a better use of resources instead of modeling if too many site specific parameters, such as soil moisture and soil type are unknown, or if there is too much variability across the site for other parameters such as building construction. Supplemental measurements might also be wise if previous sampling was performed after recent precipitation or unusual meteorological events (ITRC guidance, D-27 and D-28).

Before using a model or requesting additional environmental measures, check requirements of state specific guidance for vapor intrusion. Some state guidelines require additional investigation if groundwater and/or soil gas measurements exceed published screening values.

Step 12) Request further site specific information and measurements if there are no indoor air data and sufficient information is not available to estimate indoor air concentrations based on observed attenuation factors or modeling.

When requesting additional information, consider both the quantity and quality of environmental measurements needed to estimate an exposure dose. If multiple occupied buildings may be impacted, how many and which buildings should be sampled? Consider the cost and intrusiveness of both subslab sampling and indoor air sampling. For additional information on alternatives for additional environmental measurements, health assessors should review Chapter 3 of the ITRC vapor intrusion guidance.

Step 13) If a valid exposure dose can be estimated from information discussed in Part II, proceed to evaluate the public health implications as described in the Public Health Assessment Guidance Manual.

Step 14) Follow the PHAGM to provide the appropriate Public Health Conclusions, Recommendations, and Public Health Action Plan.

Internet References and Resources

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Appendix A.

Lessons learned from health assessments of Ohio vapor intrusion sites

From Robert Frey, Ph.D., Ohio Department of Health

- Current vapor intrusion models have limited utility with regard to predicting impacts of vapor intrusion on residential and commercial structures

- Vapor intrusion sites have to be investigated and evaluated on a site specific basis – Ohio sites have indicated numerous exceptions to some of the generalities that have been made to date with regard to the vapor intrusion pathway

- These evaluations are only as good as the data collected to support these investigations – more accurate diagnoses come when you have all of the data – groundwater, deep soil gas, sub-slab soil gas, and indoor air – not just one or two pieces of the puzzle

- Soil gas levels are often an order of magnitude or more higher than groundwater concentrations (ex. Springfield Street site: maximum PCE in groundwater = 257 ppb versus PCE in soil gas at 7,700 ppb/v; Behr-Dayton site: maximum TCE in groundwater = 16,000 ppb versus TCE in soil gas at 160,000 ppb/v)

- Residences with crawl spaces and dirt floors may actually have lower levels of vapor-phase VOCs indoors than homes with concrete basements (homes with crawl spaces are often vented to the outside and typically are less "energy efficient" than homes with finished basements)

- Important to establish a public health team (including the local health department) to support the environmental protection agencies enforcement activities and establish good contacts and communications with the impacted communities to better facilitate the investigations and corrective actions that might be taken

Appendix B.

Background VOC Studies References

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