



INTERSTATE TECHNOLOGY & REGULATORY COUNCIL

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INTERSTATE TECHNOLOGY & REGULATORY COUNCIL



Background Document

Vapor Intrusion Issues at Brownfield Sites



December 2003

Prepared by
The Interstate Technology & Regulatory Council
Brownfields Team

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Established in 1995, the Interstate Technology & Regulatory Council (ITRC) is a state-led, national coalition of personnel from the environmental regulatory agencies of some 40 states and the District of Columbia; three federal agencies; tribes; and public and industry stakeholders. The organization is devoted to reducing barriers to, and speeding interstate deployment of, better, more cost-effective, innovative environmental techniques. ITRC operates as a committee of the Environmental Research Institute of the States (ERIS), a Section 501(c)(3) public charity that supports the Environmental Council of the States (ECOS) through its educational and research activities aimed at improving the environment in the United States and providing a forum for state environmental policy makers. More information about ITRC and its available products and services can be found on the Internet at <http://www.itrcweb.org>.

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Brownfields Team**

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This document is dedicated to the memory of Bill Librizzi, a dedicated member of the Interstate Technology & Regulatory Council (ITRC) Brownfields Team who passed away in Italy in 2003. The Brownfields Team honors Bill as our valued colleague and misses him as our cherished friend.

The members of the ITRC Brownfields Team wish to acknowledge the individuals, organizations, and agencies that contributed to this background document. The team wishes to thank the Brownfields Team leader, Christine Costopoulos and former Team Leader, Terri Smith, for their guidance and support. The effort to produce this document was directed by the Brownfields Team's Vapor Intrusion Subteam, led by Ken Gilland and supported by Megan Cambridge, Gary Riley, and Mark Nielsen. Many members of the Brownfields Team supplied valuable content and input during the preparation of the document, including Kai Steffens, Gail Jeter, Joe Hickey, Al Yonk, Madeleine Kellam, Bill Mundy, J. R. Capasso, Annette Gatchett, Roger Argus, Ann Vega, Barry Brawley, Leah Yasenchak, Richard Mach, Kim Parker Brown, and Mike Verchick.

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EXECUTIVE SUMMARY

Vapor intrusion is emerging as a potential concern at thousands of sites across the nation. These sites can include brownfield redevelopment, new development, and other contaminated sites. Recent observations have brought to light the potential importance of vapor intrusion as an exposure pathway. The U. S. Environmental Protection Agency (EPA) defines vapor intrusion as the “migration of volatile chemicals from the subsurface into overlying buildings” (EPA 2002). Released to soil and/or groundwater, volatile organic compounds such as trichloroethylene, tetrachloroethylene, or benzene can emit vapors that may migrate through subsurface soils and into the indoor air spaces of overlying buildings in ways similar to that of radon gas seeping into homes.

The contaminants associated with vapor intrusion can typically be associated with releases to soil and groundwater from properties such as gas stations, dry cleaners, and industrial facilities. According to the U.S. General Accounting Office, an estimated 200,000 underground storage tanks currently in operation may be leaking (GAO 2002). In 1998, EPA estimated that there were 36,000 active dry cleaning facilities in operation in the United State. In 2001, it was estimated that 75% of the active dry cleaner sites are contaminated with volatile chemical solvents.

Vapor intrusion need not be a barrier to redevelopment of brownfield sites. Several states and EPA have developed methods to screen for sites with potential vapor intrusion concerns. Building on techniques used for radon abatement, strategies have been developed that can reduce or eliminate indoor air contaminant concentrations. In most cases, the potential risks can be controlled through source control of the contaminant of concern, ventilation improvements to buildings and structures, air treatment methods, and land use controls.

This document, intended to be a resource for stakeholders involved with redevelopment projects, provides an overview of vapor intrusion, the type of contaminants that may have vapor intrusion potential, the potential of brownfield sites to have indoor air exposure from vapor intrusion, and the steps that can be taken to limit exposures. It includes discussion of state and federal approaches for determining whether vapor intrusion may pose risks and case studies to illustrate site conditions that are typical when vapor intrusion impacts indoor air quality.

Vapor intrusion is not only a concern here in the United States; other countries around the world are dealing with this emerging issue. The Brownfields Team is fortunate to have had international participation in the development of this document. To acknowledge this we have included a German language summary of the document, the German perspective on vapor intrusion issues and case studies of affected sites in Germany.

EXECUTIVE SUMMARY (German version)

Intrusion flüchtiger Schadstoffe aus dem Untergrund in Gebäude

Eine Veröffentlichung des ITRC¹ Brownfields Team

Key words: Intrusion, Flächenrecycling, Altstandort, VOC, Leitfaden, Handlungsanleitung, Gebäude, Innenraumluft, Migration, Öffentlichkeitsarbeit

Profil und Inhalt des Berichts

Intention of this Text

The following German text summarizes the mission and the content of the document. It gives the German reader an impression on the nature of information given in the document and will help potential readers to find the document in Internet searches.

Die Thematik

Intrusion flüchtiger Schadstoffe (“Vapor Intrusion”) ist seitens der U. S. Environmental Protection Agency (EPA) definiert als “Die Migration flüchtiger Verbindungen aus dem Untergrund in darüber befindliche Gebäude” (EPA 2002).

Hintergrundbericht

Diese Veröffentlichung soll all denen als Quelle von Hintergrundinformationen dienen, die in irgendeiner Weise in Projekte des Flächenrecycling eingebunden sind. Es betont den Überblick über das gesamte Spektrum der Thematik des Eindringens flüchtiger Verbindungen in Gebäude anstatt detailliert auf Einzelaspekte einzugehen. Es erläutert die Schnittstellen zwischen Einzelaspekten und enthält eine große Zahl von Quellenangaben, die dem Leser bei weiteren Recherchen nützlich sein können.

Inhalt des Berichts

In Kürze:

Der Bericht gibt einen Überblick über die Thematik, die dafür relevanten chemischen Verbindungen, die Bedeutung des Themas für die Wiedernutzung von Recycling-Flächen und Schritte zur Erkundung und Vermeidung von Belastungen. Eine kurze Vorstellung der gegenwärtig gängigen US-amerikanischen Regeln und Leitfäden zur Gefährdungsabschätzung und eine Sammlung von typischen Fallbeispielen runden die Darstellung ab.

Bedeutung der Thematik auf Recycling-Flächen:

Bei weitem nicht auf jeder wiedergenutzten Recycling-Fläche stellt die Thematik der Intrusion flüchtiger Verbindungen ein Problem dar. Und wenn es tatsächlich relevant sein sollte, stehen durchaus kostengünstige Verfahren zur Abhilfe zur Verfügung. Flächenrecycling-Projekte sind jedoch im Regelfall extrem komplex, was die Gefahr erhöht, dass potenzielle Probleme übersehen werden, so z. B. auch die hier diskutierte Thematik.

Flüchtige organische oder chlororganische Verbindungen (wie z. B. Benzol, Trichloroethen [TCE] oder Tetrachloroethen [PCE]) können aus entsprechenden Verunreinigungen des Bodens

oder des Grundwassers freigesetzt werden und in Gebäude migrieren, ähnlich wie es bereits vom Radon seit längerem bekannt ist. Die relevanten Schadstoffe kommen typischerweise z. B. auf Altstandorten von Tankstellen, chemischen Reinigungen oder auch auf industriellen Altstandorte vor.

Eine Besonderheit von Flächenrecycling-Projekten ist es jedoch, dass sie auch dann bereits Schaden nehmen können, wenn gar keine Gesundheitsrisiken bestehen. Beispiele zeigen, dass eine aus unbestimmten Ängsten resultierende Stigmatisierung bereits zur Zurückhaltung bei Finanzierungszusagen oder zu Hindernissen in der Vermarktung führen kann. Aus diesem Grund ist es für das Flächenrecycling besonders wichtig, verlässliche und handhabbare Vorgehensweisen zu entwickeln, die eine Erkennung und Bewertung von Problemen mit flüchtigen Schadstoffen ermöglichen. Ferner müssen die Wege und Verfahren zur Vermeidung oder Beseitigung von Innenraumluft-Belastungen publiziert und angewendet werden, um zu zeigen, dass das Eindringen flüchtiger Schadstoffe bei richtiger Planung und Handhabung kein Hindernis für die Wiedernutzung von Altstandorte sein muss.

Gebäudestruktur und Innenraumluft-Belastung:

Der Bericht beschreibt die Zusammenhänge zwischen der Toxizität, dem Migrationspotenzial und verschiedenen Arten von Baukörper und betont dabei die wesentliche Abhängigkeit der Innenraumluftbelastung von der Belüftungssituation der Gebäude. Die daraus resultierenden Risiken werden im Zusammenhang mit den gesetzlichen Regeln für die Innenraumluft-Qualität dargestellt.

Die Grundlagen der Gefährdungsabschätzung in Bezug auf die Exposition mit flüchtigen Schadstoffen werden hinsichtlich der Datengewinnung, der Bewertung und der Kommunikation in die Öffentlichkeit kurz dargestellt. Die Darstellung der Grundlagen wird ergänzt durch Erläuterungen mathematischer Modelle (Johnson & Ettinger, VOLASOIL) und Untersuchungsstrategien zur Gewinnung der Eingabedaten für die Modellierungen. Insbesondere wird auf die Vor- und Nachteile, auf mögliche Fehlerursachen und auf Grenzen der Einsetzbarkeit von Basisdaten und Modellen hingewiesen.

Der großen Bedeutung der Risiko-Kommunikation als Bestandteil der Öffentlichkeitsarbeit in Flächenrecycling-Projekten wird in dem Bericht durch eine Liste von Grundregeln und Angaben weiterführender Leitfäden etc. Rechnung getragen.

Abwehrstrategien:

Der Bericht enthält kurze Beschreibungen von Verfahren, mit denen Innenraumluft-Belastungen reduziert oder vermieden werden können. Dazu gehören sowohl passive als auch aktive Verfahren für bereits bestehende und neu zu errichtende Gebäude. Die Verfahren sind in Tabellen kurz erläutert und bezüglich ihrer kurz- und langfristigen Wirksamkeit, ihrer Anwendbarkeit und ihrer Kosten charakterisiert, wobei besonders auf Kostenfaktoren und –komponenten hingewiesen wird.

Bundes- und Bundesstaatliche Regeln:

Auf die Bedeutung der Verfügbarkeit von Werkzeugen für die Erkennung und Bewertung von Risiken wurde oben bereits hingewiesen. Die amerikanischen Bundesstaaten und die

Bundesregierung haben ein umfangreiches Schrifttum mit Regeln, politischen Vorgaben und Leitfäden veröffentlicht. Der vorliegende Bericht enthält Quellenangaben und Hyperlinks auf die Leitfäden aus 14 Bundesstaaten, der U.S. EPA und des Department of Energy (DoE). Vier Beispiele aus den Bundesstaaten und die beiden Leitfäden der Bundesdienststellen werden im Bericht kurz erläutert, um der Leserschaft Eindrücke darüber zu vermitteln, ob diese Leitfäden für die eigene Fragestellung hilfreich sein könnten. Zusätzlich enthält der Bericht Informationen zum Stand der Diskussionen und zu den rechtlichen Rahmenbedingungen in Deutschland.

Schlußfolgerungen im Bericht:

Die Schlußfolgerungen umfassen die Feststellung, dass die Thematik der Intrusion flüchtiger Schadstoffe in Gebäude in vielen Flächenrecycling-Projekten mehr Aufmerksamkeit verdient. Gleichwohl ist deutlich festzustellen, dass die Relevanz der Thematik bei weitem nicht in jedem Projekt gegeben ist, sondern dass die Forderung lautet, sie hinreichend zu prüfen. Für die Fälle, in denen die Relevanz gegeben ist, stehen Verfahren zur Sanierung oder Vorbeugung zur Verfügung. In jedem Fall kommt einer wohlüberlegten Vorgehensweise und Planung sowie der Öffentlichkeitsarbeit überragende Bedeutung zu. Die Entwicklung von rechtlichen Vorgaben und von Handlungsanleitungen schreitet rapide voran.

Anhänge:

Die Anhänge des Berichts enthalten u. a. detailliertere Informationen zu den relevanten chemischen Verbindungen und zu den mathematischen Modellen. Ferner sind eine Reihe von Fallbeispielen aus den USA und aus Deutschland dargestellt.

Mehr Informationen zu diesem Bericht und zu den Aktivitäten der Arbeitsgruppe sind zu erhalten vom Leitenden Autor des Berichts, Ken Gilland (krig@rti.org), von der Leiterin der Arbeitsgruppe, Christine Costopoulos (cjcostop@gw.dec.state.ny.us) und vom Ansprechpartner für die Deutschland betreffenden Aspekte, Kai Steffens (steffens@probiotec.de)

Anmerkung 1

Zum ITRC und seiner Arbeit:

Der ITRC ist der Interstate Technology and Regulatory Council, eine von den Bundesstaaten getragene, nationale Vereinigung von Mitarbeitern von Ordnungs- und Fachbehörden aus über 40 US amerikanischen Bundesstaaten, dem District of Columbia; drei US-Bundesämtern, aus Stämmen der Amerikanischen Ureinwohner, aus Beteiligten der interessierten Öffentlichkeit und aus der privaten Wirtschaft. Ziel ist die Beseitigung von Hindernissen und die Förderung des Einsatzes besserer und kostengünstigerer innovativer Sanierungstechniken. Die ITRC Arbeit dient dem vertieften Verständnis der Vorteile und Risiken innovativer Umweltschutz- oder Sanierungstechnologien und setzt diese Informationen in Leitfäden und Arbeitshilfen für Genehmigungsverfahren um.

Generelles Ziel ist die Verbesserung der Akzeptanz neuer Verfahren durch Sammlung und Verdichtung von Informationen und den Erfahrungsaustausch, der durch die Vertreter der Genehmigungsbehörden selbst getragen wird. Aufgrund seines Netzwerkes von mehr als 6000 Mitgliedern aus allen Umweltfachgebieten, fungiert der ITRC als ein einzigartiger Katalysator für den Dialog zwischen den Ordnungsbehörden und der Fachöffentlichkeit.

Mehr Informationen über den ITRC und die Arbeitsergebnisse sind verfügbar unter **www.itrcweb.org**.

Anmerkung 2

Die Mitarbeit der deutschen Teammitglieder ist Teil eines gemeinsamen Forschungs- und Entwicklungsvorhabens des Deutschen Bundesministeriums für Bildung und Forschung (BMBF) der amerikanischen Umweltbehörde United States Environmental Protection Agency (US EPA).

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VAPOR INTRUSION ISSUES AT BROWNFIELD SITES

1. INTRODUCTION

Residents of the community of Mountain View, California were invited recently to an “open house” meeting conducted by the U. S. Environmental Protection Agency (EPA). At the meeting, the community learned that industrial chemicals had been released into the ground in their area many years previously. Prior to the residential development of the area, several semiconductor and electronics manufacturing operations, as well as research facilities, had been located in the area. These facilities had used chemicals called “chlorinated solvents” in the manufacture of computer components. The solvents had been stored in underground tanks, some of which had developed leaks. The leaking tanks had contaminated the groundwater, which had spread the contamination along the path of groundwater flow. Although a treatment system had been installed in the 1980s to begin cleanup of the contamination, EPA advised the community that the “plume” of solvent-contaminated groundwater may have moved underneath homes and businesses in the Mountain View community.

Certain chemicals, such as the industrial solvents in the Mountain View example, evaporate readily. These chemicals are described as “volatile.” Because these chemicals evaporate so easily, even into the air spaces in the soil, the potential exists for chemical vapors to rise through the soil and enter homes and businesses. This phenomenon, the migration of volatile chemicals from the subsurface into overlying buildings, is known as “vapor intrusion.” A generalized diagram of vapor intrusion at residential sites is shown in Figure 1-1.

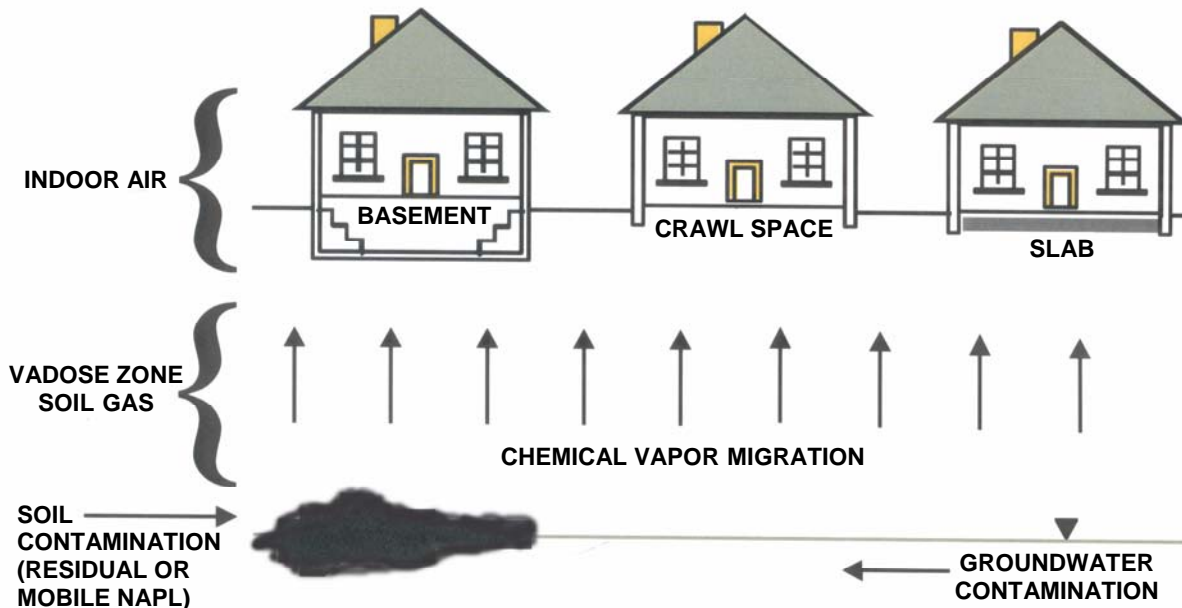


Figure 1-1. Generalized diagram of vapor intrusion in a residential setting from a groundwater source (based on Johnson 2002).

The hazards associated with a contaminant release depend on the amount of contaminant released, the toxicity of the contaminant, and the site-specific conditions that affect the spread of the contaminant. The Mountain View community is now working with EPA to conduct additional testing of soil and groundwater. These tests will determine whether there is any actual risk from intruding vapors and will point the way to developing a remedy if a vapor intrusion risk is identified.

The experience of Mountain View is not unique. All across the country, releases from such small operations as gas stations and dry cleaning facilities, as well as larger facilities such as manufacturing operations, have resulted in contaminated soil or plumes of groundwater contamination. Although this situation is not new, it is only in recent years that concerns have arisen about the potential effects of vapor intrusion resulting from such contaminant releases. EPA has turned its attention to developing methods to evaluate the potential for vapor intrusion. In concert with that effort, EPA is also working to develop strategies to abate vapor intrusion hazards (EPA 2002).

There is growing concern in many parts of the country about the waste of resources caused by urban sprawl. Many communities have begun to take an active interest in revitalizing and redeveloping city centers to combat this trend. These efforts often include efforts to improve the quality of city life by actively converting in-town industrial sites to green space and recreational uses. In addition, there is growing interest in placing new industrial facilities on old industrial properties as an alternative to building in undeveloped “greenfield” areas. Redevelopment often involves consideration of a site may have been contaminated through past uses of the property. Redevelopment projects of this type are typically called “brownfields.”

This document is designed to look at the vapor intrusion issue from a brownfields viewpoint. Brownfields are typically defined as “abandoned or underutilized” properties. This description applies to a wide variety of sites including, but not limited to, industrial property, old gas stations, vacant warehouses, former dry cleaning establishments, and sites that contain petroleum products, as well as mine-scarred land. Brownfields are located in almost every community in the United States. Because many brownfields have a history of industrial use, vapor intrusion may be a consideration for redevelopment of these sites. Vapor intrusion, however, need not be a barrier to redevelopment.

This document discusses the concept of vapor intrusion, the type of contaminants that may pose a risk of vapor intrusion, and the steps that can be taken to control or abate these risks. There are also discussions of state and federal approaches to determining vapor intrusion potential and case studies to illustrate site conditions that may impact indoor air quality through vapor intrusion. A list of acronyms used throughout the document is provided in Appendix A.

2. INDOOR AIR QUALITY

Indoor air exposure pathways can be complex, and indoor air quality can be affected by many factors other than vapor intrusion, including the following:

- combustion products from oil, coal, wood, and natural gas;
- off-gassing of building materials and furnishings such as paints and carpets;
- deterioration of asbestos-containing materials like insulation or spray-on surfacing;
- household products like solvents and glues;
- internal contaminants like mold spores;
- emissions from industrial process equipment and operations; and
- external sources of contamination such as vehicle emissions.

Although numerous sources affect indoor air quality, this document focuses on only the exposure pathways of vapor intrusion from contaminated soils and groundwater.

2.1 Indoor Air and Building Design

The process of outdoor air replacing indoor air is called “air exchange.” The relative “tightness” of a building is determined by examining the rate at which this replacement takes place (the “air exchange rate”). The American Society of Heating, Refrigerating, and Air-Conditioning Engineering recommends a general exchange rate of 0.35 exchanges per hour for residential buildings. The recommended rate for a specific structure may be higher, depending on factors such as the number of people in the building and whether there are fuel-burning appliances (Hughes, Johnson, and Payne 1997).

In buildings, air exchange between the interior and exterior environments takes place by natural ventilation through open windows and doors, by mechanical ventilation systems, or by the process of infiltration. Infiltration is the movement of air through gaps in closed windows, cracks in the walls or foundation, or through chimneys that are not in operation. Infiltration and natural ventilation are caused by pressure gradients between indoor and outdoor air, or between indoor air and vapors in the soil (soil gas). The ventilation system of a building can cause negative pressure during operation that pulls air from the subsurface into the building or can cause positive pressure that minimizes air infiltration.

Indoor air contaminants tend to accumulate in modern buildings because these structures are designed to limit the exchange of air with the outer environment. For example, windows in many modern buildings serve purely aesthetic functions and cannot be opened. Limiting air exchange in this manner minimizes the amount of energy expended on heating and cooling, protects the contents of the building from moisture, and reduces the intrusion of outside noise sources. However, a consequence of tight building design may be the accumulation of vapors from many sources, including vapor intrusion.

2.2 Vapor Risks

2.2.1 Vapor Exposure Risks

When evaluating the ways that people can be exposed to contaminants, it is important to determine how they may come into contact with the material. Exposure routes may include eating or drinking contaminated material (ingestion), skin contact (dermal), and breathing contaminant vapors (inhalation). The exposure route of concern for vapor intrusion is inhalation.

Contaminants in soil and groundwater can vaporize, travel through the soil, and enter an indoor air space. These contaminants can vaporize from the soil and groundwater immediately under a structure, or can migrate through preferential pathways such as abandoned sewers or underground utility lines (EPA 2003). When these vapors accumulate in indoor air spaces, the potential for inhalation arises. Various types of contaminants may become vapors. Typically, those with the highest potential to vaporize are the most likely to pose vapor intrusion concerns. The compounds most commonly associated with vapor intrusion are volatile organic compounds (VOCs). Some non-VOC contaminants (e.g., mercury) can also be a vapor intrusion risk. Also, some VOCs can exist as a separate phase (not dissolved in water). These nonaqueous-phase sources are a potential risk for vapor intrusion, especially in soils. Some studies have indicated that other organic contaminants that have lower volatility than VOCs may have a slight potential to be a vapor intrusion risk (Davis et al. 2003).

VOCs are found in fuels, cleaning solutions, industrial solvents, many pesticides and herbicides, and dyes. These compounds can exist as a vapor at atmospheric temperature and pressure. VOCs dissolved in groundwater are more likely to volatilize at high concentrations if the groundwater temperature increases or if the pressure on the groundwater decreases. The strength of this tendency to vaporize is specific to the type of contaminant and is characterized by a property called the Henry's law constant, named for the English chemist William Henry (1774–1836), who researched the relationship between gases and liquids. An organic compound with a Henry's law constant greater than 10^{-5} is considered to be a VOC.

There are other properties of contaminants that are very important to consider when it comes to determining the inhalation risk associated with the compound, including the toxicity of the compound, its persistence in the environment, and its ability to pass through the human lung and into the bloodstream. Some chemicals are considered to cause cancer (carcinogens) while others may cause different health effects. Some contaminants can degrade over time to products that may be more or less hazardous than the original contaminant. Appendix B contains a list of chemicals that have sufficient toxicity and volatility to be considered a vapor intrusion risk by EPA.

The Occupational Safety and Health Administration (OSHA) regulates exposures to compounds used in industrial settings. OSHA has established permissible exposure levels (PELs) to limit the risks that workers may face from contaminants. PELs are established for specific industrial compounds where workers have been trained on the use and hazards associated with the compound. PELs can be defined in two ways: the maximum allowable concentration for a single exposure ("ceiling value") or the exposure level allowed during an eight-hour period ("time-

weighted average”). For vapor intrusion, the time-weighted average is most applicable due to the low contaminant concentrations and long exposure times encountered. For example, tetrachloroethylene (PCE), a common chemical used in dry cleaning industry, has a regulatory time-weighted average PEL value of 100 parts per million (ppm) in indoor air (Kamrin 2001).

OSHA PELs may not apply in a brownfields setting if the regulated compound is present due to a release rather than to an industrial exposure. In this case, risk-based approaches to determine exposure can be used. Risk assessment approaches attempt to quantify the risks associated with vapor intrusion to ensure that human health is protected. Assessments may be used to determine what level of contaminants can pose an inhalation risk to human health. These risks are based on the duration of the contaminant exposure and the concentration and toxicity of the contaminant.

For example, the California Regional Water Quality Control Board, San Francisco Bay Region reported that trichloroethylene (TCE) releases contaminated local groundwater at a former freeze-drying facility in the San Francisco Bay area. Although OSHA PELs for TCE clearly applied while the business was in operation, the standards no longer applied following closure of the facility because the compound was no longer in use. The building remained in use as a warehouse. Once it was determined that the contaminants from the groundwater affected the indoor air quality of the warehouse, exposure was evaluated using risk-based screening levels rather than OSHA standards.

2.2.2 Acute Hazards

This document does not specifically address acute hazards, which are rare but can happen under certain circumstances. Some VOCs are very reactive. For example, if a sufficiently high concentration of these compounds accumulates in a building, explosion is a risk. Such high concentrations are typically indicated by a strong chemical, gasoline, or solvent odor. If these conditions are encountered, individuals should evacuate the building, and proper authorities should be notified immediately. Anoxic conditions can result when gases replace oxygen in the building, creating conditions that may endanger human health. Again, if these conditions are encountered, individuals should evacuate the building and notify authorities immediately.

2.3 Brownfields and Vapor Intrusion

Vapor intrusion can be an issue for those interested in brownfield redevelopment because it can be a hidden source of contamination. The chemicals that have volatilized are underground and may have entered the environment some distance from the site being considered for redevelopment. Under many conditions, there is no strong chemical odor associated with the contaminant. The contamination may remain undetected during the due diligence process for property transfers because environmental audits tend to rely on information about releases that have previously been reported to regulatory agencies. Also, the migration of a contaminant plume can be difficult to predict or model and may change through time.

Any area can be affected by vapor intrusion; however, redeveloped brownfield sites may have a greater risk than undeveloped areas. Past activities at brownfield sites may have contaminated soil and groundwater. Many of these sites are in urban areas, where they may be close to sites

contaminated with VOCs. Often, brownfield sites are in communities where many businesses are in close proximity to each other. Also, older buildings that are redeveloped may have damaged foundations, which can increase the potential for vapor intrusion.

Redevelopment in areas of former industrial/manufacturing processes or commercial establishments pose challenges. The desire to quickly convert these properties may encourage the renovation and construction of new buildings without taking into consideration potential vapor intrusion issues. Upgrading structures to meet building codes and energy conservation requirements can create tight buildings that may enhance the effects of vapor intrusion.

Planning becomes key to understanding the potential for vapor intrusion to become an issue. For sites with known contamination problems, sufficient data may exist to determine the concentrations of the contamination in soil, soil gas, and groundwater and to calculate the level of risk from potential exposures. To protect public health, the risk assessment process needs to consider all current land uses. The planning process should also take into account ways the site could be used in the future.

Screening studies may be conducted at some brownfield sites to determine whether vapor intrusion is a potential concern. Again, it is important to note that vapor intrusion will not be an issue at all brownfield sites. When it is encountered, abatement strategies—as discussed in Section 4—can be developed that reduce vapor intrusion risks.

3. THE CONCEPT OF RISK

Risk can be defined as the chance some harmful event may occur (U.S. Army Corps of Engineers n.d.). In the context of vapor intrusion, risk is the chance that inhalation of contaminant vapors can impact human health. It is important to understand how risks are assessed, the data on which risk assessments are made, and how to communicate this information to stakeholders.

3.1 Exposure Assessment

In the context of this document, exposure assessment is a relatively new science. It was used in the first half of the 20th century to establish health and safety codes and standards. As summarized by the U.S. General Accounting Office (GAO) in 2001, “The development of chemical risk assessment procedures has traditionally followed two different tracks, one for assessments of cancer risks and another for assessments of non-cancer risks.” Assessments of cancer risks are based on the concept that there is no “threshold value” below which the chemical would not cause adverse effects; assessments of noncancer risks are based on the assumption that such a threshold value does exist. For this reason, exposure assessments for compounds suspected to be human carcinogens typically yield lower acceptable contaminant concentrations (GAO 2001).

The National Research Council (NRC) has identified four steps in the exposure assessment process:

- Hazard identification (what substances can impact humans or the environment)
- Dose-response assessment (how the magnitude of the exposure relates to the severity of the impacts)
- Exposure assessment (how often the exposure occurs, how long the exposure is, and what pathways are associated with the exposure)
- Risk characterization (combining the first three steps to come to conclusions about the magnitude and nature of the risks associated with the compound) (EPA 1986, NRC 1983)

When properly conducted, exposure assessments enable decision makers and stakeholders to make informed choices on issues involving contaminant exposures. Exposure assessments should not preclude options; rather they should provide a framework for discussion on ways to limit risks to acceptable levels. For sites with potential vapor intrusion concerns, there is a need to estimate vapor intrusion exposure. The exposure assessment should determine the exposure that will exist at a site following the redevelopment process and ensure that risk management decisions, including cleanup action decisions, are protective of future site uses. Exposure assessment models have been developed to estimate these risks.

Some exposure assessment models are simple analytical solutions to governing equations. Models enable a calculation of the current risk attributable to contamination known or suspected to be present at a site. They may also be used to establish threshold concentrations of a contaminant in soil or groundwater that, if exceeded, are likely to result in unacceptable exposure to site users under the anticipated reuse. Modeling has a long history of application in many scientific disciplines and is well established in the fields of groundwater flow and contaminant transport. Within the last 15 years, models have been developed to address the indoor air exposure pathway.

Modeling data are often based on or augmented by the collection of site-specific data in the form of soil gas or groundwater sampling. The method used in sampling can have a significant impact on the accuracy of the sample results. As more data are collected for vapor intrusion studies, more realistic estimations of the vapor intrusion issue will be possible.

3.2 Mathematical Modeling

Models are mathematical computer programs that use a complex set of mathematical equations to describe physical processes such as the movement of vapors and chemicals through the environment. Models can make accurate representations and predictions of the current nature of contamination and its future behavior. However, care must be taken to ensure that models are used correctly and appropriately.

The user must evaluate many site-specific factors to select the proper model, including the type of contaminant(s), building features, soil properties, and groundwater characteristics of the site. Much of this process depends on the amount and quality of the knowledge about site conditions and any contaminants. However, even when data are lacking or only sparsely available, models

can be used to evaluate the impact that uncertainty has on current and future risk from the indoor air pathway. Screening-level models using conservative assumptions can establish whether vapor intrusion into indoor air is a potential problem at a particular site. Screening-level models will quickly eliminate some sites that do not have a vapor intrusion risk. For other sites, additional data gathering can be targeted to those parameters that will provide the greatest reduction in uncertainty. Such processes can ensure efficient use of the limited funds available for environmental sampling. This iterative approach is consistent with the Triad approach to dynamic sampling work plans addressed in EPA and Interstate Technology & Regulatory Council (ITRC) guidance.

Forward contaminant transport modeling uses the chemical contamination measured or estimated at a site to make predictions regarding the current or future indoor air concentrations of VOCs in buildings. One of the most widely used models for this purpose is the Johnson and Ettinger (J&E) model for subsurface vapor intrusion into buildings (Johnson and Ettinger 1991). Appendix C contains more information regarding this model. For this model to be correctly applied, a wide variety of site, soil, and chemical parameters must be entered. For the complete list and technical basis for each parameter, see the J&E model user's guide (EPA 1997).

3.3 Sampling

When using models to screen a potential site to rule out the possibility of vapor intrusion, sampling is necessary. The most recent EPA guidance on sampling discusses the various types of sampling that could be conducted to determine vapor intrusion exposures: groundwater sampling, soil gas sampling, subslab sampling under a building, or indoor air sampling (EPA 2002). The type of sampling required depends on several factors, including the type of structure being sampled. Figure 3-1 shows one possible sampling strategy for different types of houses.

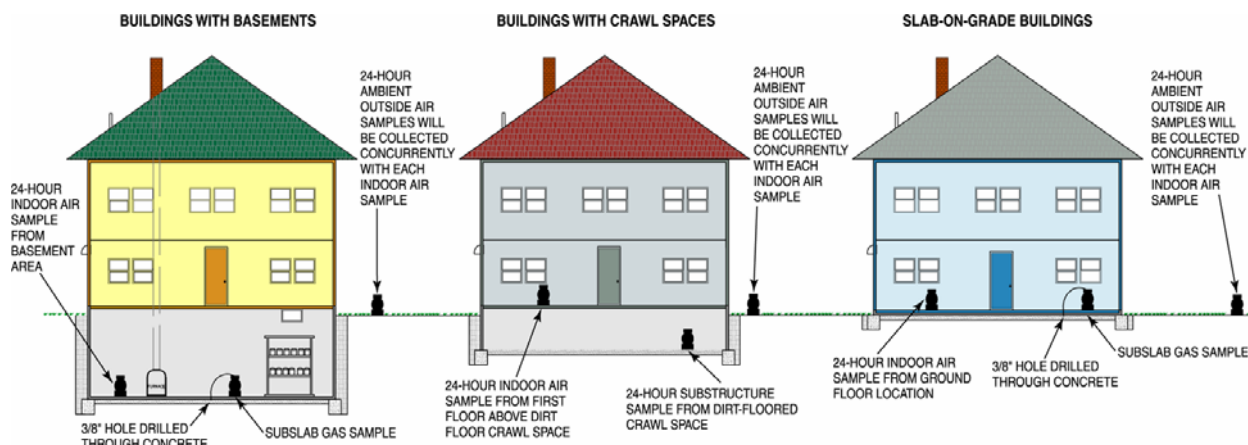


Figure 3-1. Vapor intrusion sampling in residential areas. (modified from Sanborn, Head, and Associates 2003)

3.3.1 Groundwater Sampling

One common method for evaluating vapor intrusion is through groundwater sampling. To evaluate the potential for contaminants to volatilize from the groundwater and enter nearby

buildings, it is important to determine how deep the water table is under the building and to sample the area near the top of the water column. It is also necessary to evaluate how VOCs disperse after they are volatilized from the groundwater. This is called the “effective diffusion coefficient.” There are standard equations that can be used for these calculations, but actual vapor intrusion is affected by site-specific factors.

3.3.2 Soil Gas Sampling

For several years, soil gas samples taken near buildings were used to determine vapor intrusion potential. The advantage of this sampling technique is that it is less expensive than groundwater sampling and does not require access to the building. However, recent studies have found that there can be considerable variation between soil gas samples taken near buildings and subslab samples. These differences are attributed partly to differences in the temperatures and pressures in the two settings. Also, there can be significant differences between the moisture content of soils under a building and those adjacent to the structure.

3.3.3 Indoor Air and Subslab Sampling

The most recent EPA guidance recommends that subslab sampling or indoor air sampling be conducted if screening does not rule out the threat of vapor intrusion. Indoor air sampling may seem to be the simplest way to measure potential vapor intrusion issues. However, indoor air sample results can be affected if something in the building was recently dry cleaned, there is an open container of varnish, or gasoline is stored in a basement. Occupant activities such as smoking can also influence results. Indoor air contaminant concentrations can also vary considerably depending on temperature and pressure variations in the outside climate or the operation of heating or air conditioning systems. For these reasons, EPA recommends that indoor air sampling be conducted more than once and that the sampling program be designed to identify ambient outdoor air and indoor air emission sources of contamination.

Subslab sampling is considered a preferred sampling method. It enables a direct measure of the vapor concentration that is most likely to enter the structure and excludes many of the factors in buildings that can affect sampling results. Subslab sampling may not be practical in all cases. Not only does it require access to the building; it requires that holes be drilled through the lowest floor of the building to collect samples.

3.4 Risk Communication

Communicating vapor intrusion risks to the public can be difficult. Often, information about the potential indoor air situation is based on limited data. Also, vapor intrusion can be a difficult concept to explain. Communicating vapor intrusion risks can be complicated because some stakeholders may have intense reactions to the issue. The public can have a strong negative reaction to potential risks even if they are considered acceptable by regulators. Individuals may attribute a health condition to chemical exposure even when the effects are not attributable to the exposure. However, it is important to inform the affected public, community leaders, and other stakeholders at sites with vapor intrusion risks. Not only is the cooperation of the community important in any redevelopment project; in some cases determining a more complete

understanding of the vapor intrusion risks may involve neighborhood cooperation with sampling efforts.

When faced with a project involving public participation and outreach, consider using the “Seven Cardinal Rules for Risk Communication” developed for EPA:

1. **Accept and involve the public as a partner.** Your goal is to produce an informed public, not to defuse public concerns or replace actions.
2. **Plan carefully and evaluate your efforts.** Different goals, audiences, and media require different actions.
3. **Listen to the public’s specific concerns.** People often care more about trust, credibility, competence, fairness, and empathy than about statistics and details.
4. **Be honest, frank, and open.** Trust and credibility are difficult to obtain; once lost, they are almost impossible to regain.
5. **Work with other credible sources.** Conflicts and disagreements among organizations make communication with the public much more difficult.
6. **Meet the needs of the media.** The media are usually more interested in politics than risk, simplicity than complexity, danger than safety.
7. **Speak clearly and with compassion.** Never let your efforts prevent your acknowledging the tragedy of an illness, injury, or death. People can understand risk information, but they may still not agree with you; some people will not be satisfied (Covello and Allen 1988).

A variety of outreach strategies can be used to provide information to the community and gain feedback in making decisions. Public meetings may be effective to reduce intense reactions and dispel misconceptions. Experts such as geologists, scientists, toxicologists and public participation specialists can provide help by answering questions in meetings and conducting other public outreach activities. However, it is important to note that the use of technical terms and concepts used daily by scientists and government agencies can be confusing to stakeholders at public meetings, who are likely to be unfamiliar with this jargon. For this reason, it is important to design any presentation with the intended audience in mind. Other media can be used to provide the community with information and updates, such as informational fact sheets, public service announcements, and presentations targeted to specific sectors of the community. Web pages and e-mail can provide a continuous form of dialog making critical, up-to-date data available to stakeholders. Such communication can also be used to announce when additional sampling is to be conducted.

A number of books have been written on the subject of risk communication. One recommended book is *Industry Risk Communication Manual: Improving Dialogue with Communities* (Hance, Chess, and Sandman 1990). EPA has published “Considerations in Risk Communication: A Digest of Risk Communication as a Risk Management Tool,” accessible online at <http://www.epa.gov/ORD/NRMRL/Pubs/625R02004/625R02004.htm>. Also, the Agency for Toxic Substances and Disease Registry developed *A Primer on Health Risk Communication Principles and Practices* (Agency for Toxic Substances and Disease Registry 2001), accessible at <http://www.atsdr.cdc.gov/HEC/primer.html>.

4. VAPOR INTRUSION ABATEMENT STRATEGIES

When vapor intrusion conditions are found to be a problem, mitigation processes can eliminate or mitigate the potential exposure pathway. Strategies for abating vapor intrusion involve both passive and active techniques. Passive techniques can include the selective placement of buildings on the site to avoid contact with the vapors. Passive techniques can also include deed restrictions that limit proposed uses of a site (institutional controls). If passive techniques are insufficient to limit risk, more active techniques may be used to prevent the entry of vapor contamination into a building. During the planning phases of a redevelopment project, abatement strategies should be considered in the engineering design to eliminate or minimize vapor intrusion. These up-front capital costs often are less than those for installing more intrusive abatement systems as retrofits.

Active abatement strategies include the following:

- Subslab depressurization systems that can either reverse the direction of air flow or dilute the contamination with the ambient air
- Sealing the building envelope or installing vapor barriers
- Modification of the building foundation
- Site remediation technologies such as soil vapor extraction
- Indoor air purifiers or adsorption systems such as carbon filtration
- Measures to increase natural ventilation such as opening windows and doors
- Heat recovery ventilation technology
- Photoanalytical ventilation technology
- Adjustments to building heating, ventilation, and air conditioning (HVAC) systems that alter the low air exchange rates or high sustained indoor/outdoor pressure differences

In some cases, relatively simple techniques have been shown to mitigate vapor intrusion risks. Kurtz and Folkes (2002) reported that subslab depressurization had been effective in mitigating the vapor intrusion risks at over 300 residential homes in Denver, Colorado. The homes had been found to be at risk of vapor intrusion due to the presence of groundwater contaminated with 1,1-dichloroethylene (1,1-DCE). To mitigate the risk, a 90-watt fan was installed in each home. The systems were able to reduce 1,1-DCE concentrations by two to three orders of magnitude, which was below state-mandated levels. Approximately a quarter of the units required minor adjustments or upgrading after the initial installation to achieve the required level of performance. Table 4-1 summarizes some vapor intrusion remedies that may be applicable to brownfield sites. Table 4-2 summarizes the costs typically associated with these remedies.

Once an abatement strategy is in place, EPA recommends periodic site evaluations to ensure the efficacy of the strategy. It is also recommended that at sites where deed restrictions are applied to prevent restricted land uses (e.g., residential or day care uses of the site), inspections be made to ensure that site activities are consistent with those uses specified as being appropriate for human health and the environment. This is especially important as property changes ownership or leases change.

Table 4-1. Vapor intrusion remedies applicable to redevelopment sites

Remedy	Description	Effectiveness		Status
		Short term	Long term	
<i>Institutional controls</i>				
Building codes	Required for new buildings	Immediate	If regulated and monitored	
<i>New buildings</i>				
HVAC balancing	Building design for slightly positive pressure compared to outdoor	Immediate	If system and structure are maintained; regular air balancing checks needed	Established for large structures; less common for residential
Enhanced ventilation	Increased indoor ventilation	Immediate	If maintained and monitored	Unlikely for residential structures; may be acceptable in temporarily used areas (e.g., garages)
Vapor barrier	Impermeable geotextile membrane placed beneath building	Immediate if installed correctly	Effective if geotextile integrity is maintained; VOC vapors may collect beneath membrane and slowly vent into building	Feasibility depends on foundation design, typically combined with a subfoundation vent system for chlorinated solvents
Spray-on membrane and vent system	Placement of a spray-applied rubberized asphalt emulsion gas vapor membrane; an additional venting system can provide venting	Immediate if installed correctly	Effective if rubberized asphalt emulsion membrane integrity is maintained	Residential to large commercial buildings
Passive gas venting system	Collection pipes installed beneath building provide venting	Immediate	Effective unless high vapor flux requires active venting	Usually sufficient to mitigate vapor intrusion
Active gas venting system	Vacuum pump system added to passive system to extract vapors	Immediate	Effective with maintenance	Active systems are usually only required in extreme cases
<i>Existing buildings</i>				
HVAC balancing	Building design for slightly positive pressure compared to outdoor	Immediate	If system and structure are maintained; regular air balancing checks needed	Established for large structures; less common for residential
Enhanced ventilation	Increased indoor ventilation	Immediate	If maintained and monitored	Unlikely for residential structures; may be acceptable in temporarily used areas (e.g., garages)
Passive or active gas venting	As above for new buildings; trenches or boreholes must be drilled beneath the foundation	Immediate	Effective unless high vapor flux requires active venting	

Table 4-2. Costs associated with vapor intrusion remedies

Remedy	Cost	Status	Remedial cost factors cost components	Remedy uncertainties
HVAC balancing	New construction: \$0.50–\$1.00/ft ² (or 1% of total mechanical costs). Labor rates are typically \$80/hour or \$700/day for a certified air-balancing firm. These costs do not include the construction cost of the HVAC system.	Many firms use for large commercial buildings; some also use for residential buildings.	Depends on building configuration and size, quantity of air handling units, exhaust fans, variable air volume boxes, and other system components.	
Enhanced ventilation	For 7,000 m ³ (247,350 ft ³) building: New ventilation system approximately \$5,000. Upgrade existing system from one to two air exchanges per hour, ~\$2,000 (vendor estimate).	Not likely appropriate for residential buildings; may be acceptable in temporarily populated areas (garages).	Depends critically on building type, size, configuration, existing system monitoring.	Rate of vapor flux. Temporal variation in vapor fluxes.
Vapor barrier	\$4–\$50/m ² (\$0.37–\$4.65/ft ²) of building area.	Feasibility dependent on foundation design.	Size of building.	Rate and temporal variation in vapor fluxes. Vapor is beneath building.
Spray-on membrane and vent system	Spray-on membrane: ~\$2–\$3/ft ² for materials and installation. Vent system: ~\$4–\$5/ft (linear) for materials and installation.	Projects range from residential to large commercial buildings, although costs for residential buildings are less competitive.	Size of building.	
Passive gas venting system	\$10–\$50/m ² (\$0.92–\$4.65/ft ²) building area.	Usually sufficient to prevent vapor migration into buildings.	Size of building.	Vapors may require treatment before venting.
Active gas venting system	\$10–\$50/m ² (\$0.92–\$4.65/ft ²) building area; \$3,000 annual O&M. Vapor emissions system: \$20,000 capital plus \$15,000–\$20,000 O&M.	Active systems are usually required only in cases of extreme vapor flux.	Size of building.	Vapors may require treatment before venting.

5. STATE APPROACHES TO VAPOR INTRUSION ISSUES

States have been a leading force in the development of vapor intrusion regulations and policies. The Massachusetts Department of Environmental Protection was the first state agency to address this issue when the Massachusetts Contingency Plan, 310 CMR 40, was developed to deal with vapor intrusion concerns. Other states that addressed the issue in the 1990s include Connecticut and Michigan. See Table 5-1 for information on states that offer vapor intrusion regulations, policy, or guidance. The regulatory approaches taken by California, Washington, New York, and South Carolina are summarized as examples of how some state programs work.

Table 5-1. State regulations, guidance, and other publications on vapor intrusion

State	Document title	Document date
Alaska	Inhalation of Diesel Fuel in Indoor Air (http://www.state.ak.us/dec/dspar/csites/guidance/indoor_air_12_02.pdf)	December 2002
California	Screening For Environmental Concerns at Sites with Contaminated Soil and Groundwater (http://www.swrcb.ca.gov/rwqcb2/esl.htm)	July 2003
Colorado	Petroleum Storage Tank Owner/Operator Guidance Document (http://oil.cdle.state.co.us/OIL/Technical/Guidance/Documents/guidancedoc.asp)	February 1999
Indiana	Draft Procedure and Issues Report: The Vapor Intrusion Pathway (http://www.spea.indiana.edu/msras/DraftVaporReport7-08-02.pdf)	July 2002
Maine	Field Guidelines for Protecting Residents from Inhalation Exposure to Petroleum Vapors (http://www.state.me.us/dep/rwm/publications/pdf/InhalExpfg.pdf)	June 2000
Massachusetts	Indoor Air Sampling and Evaluation Guide (http://www.state.ma.us/dep/ors/files/indair.pdf)	April 2002
Michigan	Generic Groundwater and Soil Migration to Indoor Air Inhalation Criteria: Technical Support Document (http://www.deq.state.mi.us/documents/deq-erd-td5.pdf)	June 1998
Minnesota	Indoor Air Sampling at VOC Contaminated Sites (http://www.health.state.mn.us/divs/eh/hazardous/iasampling.htm - top)	May 2003
Nebraska	Risk-Based Corrective Action (RBCA) at Petroleum Release Sites: Tier 1/Tier 2 Assessments and Reports (http://www.deq.state.ne.us/Publica.nsf/a9f87abbcc29fa1f8625687700625436/66fdec793aefc4b286256a93005b8db8?OpenDocument)	February 2002
New Jersey	Indoor Air Sampling for Volatile Organic Contaminants (http://www.state.nj.us/dep/srp/guidance/indoor_air/ia_sampling_req.htm)	April 2003
Pennsylvania	Vapor Intrusion into Buildings from Groundwater and Soil under Pennsylvania (PA) Statewide Health Standard (SHS) (http://www.dep.state.pa.us/dep/subject/advoun/cleanup/2002/BoldedVaporGuidance_100702.pdf)	February 2002
Washington	Focus: Developing Air Cleanup Standards Under The Model Toxics Control Act (http://www.ecy.wa.gov/pubs/0109072.pdf)	August 2001
Wisconsin	Guidance for Professionals: Chemical Vapor Intrusion and Residential Indoor Air (http://www.dhfs.state.wi.us/eh/Air/pdf/VI_guide.pdf)	February 2003

5.1 California

Applicable Documents:

- *Active Soil Gas Advisory on How to Perform Soil Gas Sampling*, prepared for School Division, January 13, 2003.
- *Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater* Staff Guidance from the San Francisco Regional Water Quality Control Board, July 2003, accessible at <http://www.swrcb.ca.gov/rwqcb2/esl.htm>.

The California soil gas screening levels are of particular use at sites where buildings overlie VOC-contaminated groundwater or where future development is being considered. Soil gas data should be used in conjunction with soil, groundwater, and/or indoor air data to fully evaluate potential indoor air impact concerns. As noted in the document, the presence of VOCs in shallow soil gas at concentrations above the screening levels does not necessarily indicate that a significant threat to indoor air exists, but only that additional evaluation may be warranted. This could include the collection of additional soil gas samples, the collection of indoor air samples, vapor flux studies, and/or site-specific modeling. (Note that vapor flux studies are currently not considered to be adequate as a stand-alone tool for evaluating potential indoor-air impacts.)

Likewise, the presence of VOCs in shallow soil gas at concentrations below the screening levels does not indicate that impacts to indoor air will not occur. Any potential impacts are, however, expected to be below levels that would require active mitigation prior to occupation of the building. At sites where the reported levels of volatile chemicals in soil gas approach the screening levels, it may be prudent to collect indoor air samples to verify the absence of significant impacts or include passive vapor mitigation systems in new building designs as an added measure of safety. Several state and federal agencies are currently preparing guidance to address these issues. These documents, as available, will be referenced and discussed in the next update of the risk-based screening level document. The latest version of this document may be found at the San Francisco Regional Water Quality Control Board's Web site, <http://www.swrcb.ca.gov/rwqcb2/esl.htm>.

5.2 Washington

Applicable Document: *Focus: Developing Air Cleanup Standards under the Model Toxics Control Act*, accessible at <http://www.ecy.wa.gov/pubs/0109072.pdf>

Washington State has many agencies involved with air quality. The county level of government has local health jurisdictions, which deal with air quality issues that may affect the health and well-being of citizens. Regional air pollution agencies deal with air emissions from equipment or manufacturing processes that affect air quality on a large scale. Some areas of the state do not have their own regional air pollution control agency, so the Washington State Department of Ecology (Ecology) handles the regional air pollution issues in those areas through its Air Program; additionally, Ecology's Air Program oversees the various regional air pollution agencies. Also on a state level, the Washington State Department of Labor and Industries protects worker health and safety, which includes air quality issues.

Air quality issues related to brownfields and other cleanup sites are, however, handled exclusively by Ecology through its Toxics Cleanup Program, which includes both indoor and outdoor air resulting from a leak or spill (release) of a hazardous substance. The definition of a hazardous substance, as well as overall requirements for cleanup of all media, are contained in a state law—the Model Toxics Control Act (MTCA), Chap. 70.105D Revised Code of Washington. The law was passed by the voters of the state in 1988 as an initiative and as such was necessarily brief. Most of the specific requirements for cleanup were developed in the regulations associated with MTCA, Chap. 173-340 Washington Administrative Code (WAC). These regulations were amended effective August 15, 2001 and included in those changes were revisions that affected requirements and procedures for developing air cleanup standards. The specific section that deals with air cleanup standards is Chap. 173-340-750 WAC.

Air cleanup standards shall be established at sites where a nonpotable groundwater cleanup level is being established for VOCs using a site-specific risk assessment, where a soil cleanup level that addresses vapors or dust is being established, where it is necessary to establish air emissions limits for a remedial action, and at other sites as determined by Ecology. The cleanup standards must protect human health so that there are no acute or chronic health effects caused by noncarcinogenic hazardous substances, and to a cancer risk of 1 in 1,000,000 for risks caused by individual carcinogenic substances (1 in 100,000 for total cancer risk and at industrial sites). The standards must also be at least as stringent as the most stringent concentration established under applicable state and federal laws, and the concentration must not exceed 10% of the lower explosive limit for a substance or any mixture. The cleanup standards may be adjusted downward based on total site risk or if otherwise necessary to protect human health and the environment, or upward based on natural background concentrations and practical quantitation limits.

The air cleanup standard, known as a “cleanup level” when established for a specific site, must be met at a specific location known as the point of compliance. The standard point of compliance is defined as the ambient air throughout the site, which is both ambient outdoor air and air within structures. Ecology may approve conditional points of compliance for qualifying industrial properties up to the property boundary provided this step would not pose a threat to human health or the environment. Monitoring may be required to demonstrate compliance with cleanup levels. The monitoring of vapors within the soil using vapor probes may be sufficient to demonstrate compliance. It may be necessary to monitor ambient air and air within structures to demonstrate compliance if the soil vapor monitoring indicates cleanup level exceedence. Emissions caused by a remedial action must also be addressed and monitored. Contributions from off-site sources or from an industrial or commercial process or operation are not considered when determining compliance with air cleanup levels.

5.3 New York

Vapor migration is a consideration on every site on which the New York State Department of Environmental Conservation is involved. The general approach is very similar to that contained in the draft EPA guidance on vapor intrusion (EPA 2002). The first consideration is whether chemicals that have the potential for vapor intrusion (VOCs) were disposed of or released on the site and whether there are potential receptors (inhabited or proposed habitable structures).

If there is a potential for vapor intrusion, the next step is to conduct some limited sampling to determine whether these compounds exist in the soil or groundwater either on the site or migrating from the site. This sampling can consist of sampling of soil, groundwater, and/or soil gas. If at any point there appears to be a likelihood that there is a vapor intrusion impact, mitigation is implemented. Based on the results of the initial sampling effort, more detailed site-specific sampling is conducted, including additional soil gas sampling adjacent to potentially impacted structures or subslab sampling in the basements of the structures. (New York has developed a survey, reproduced below, that can be used to help evaluate vapor intrusion risks at residences.) While indoor air sampling is conducted occasionally, results may be questioned because products typically found in the home or other structures may contain the same chemicals that may be migrating through environmental media. Therefore, inventories of chemicals contained in products found in these structures must be made when indoor air sampling is performed. Whenever indoor air sampling occurs, extreme care must be exercised to remove these indoor sources.

When mitigation is called for, ventilation systems are typically installed. These are “radon type” systems, which create a negative pressure beneath the building slab and exhaust the potentially contaminated air outside using either passive or active systems.

Well and Basement Survey

Name: _____

Address of house: _____

Phone number: _____

How long have you been living at this address? _____

BASEMENTS

1. Does your house have a basement? NO YES
2. If yes, about how many feet below the ground level is the basement floor? _____
3. What is the basement used for? _____
4. Do you ever get water in your basement? NO Only after rain Usually wet
5. Do you ever get an odor in your basement that smells like driveway sealer?
 NO Occasionally Only after it rains All the time
6. Is there a floor drain in your basement? NO YES If yes, where does the drain discharge to?
 Storm sewer Sanitary sewer Seepage pit Unknown
7. What is the floor of your basement made of?
 Dirt Concrete Other (Specify) _____
8. What are the walls of your basement made of?
 Stone Concrete block Other (Specify) _____

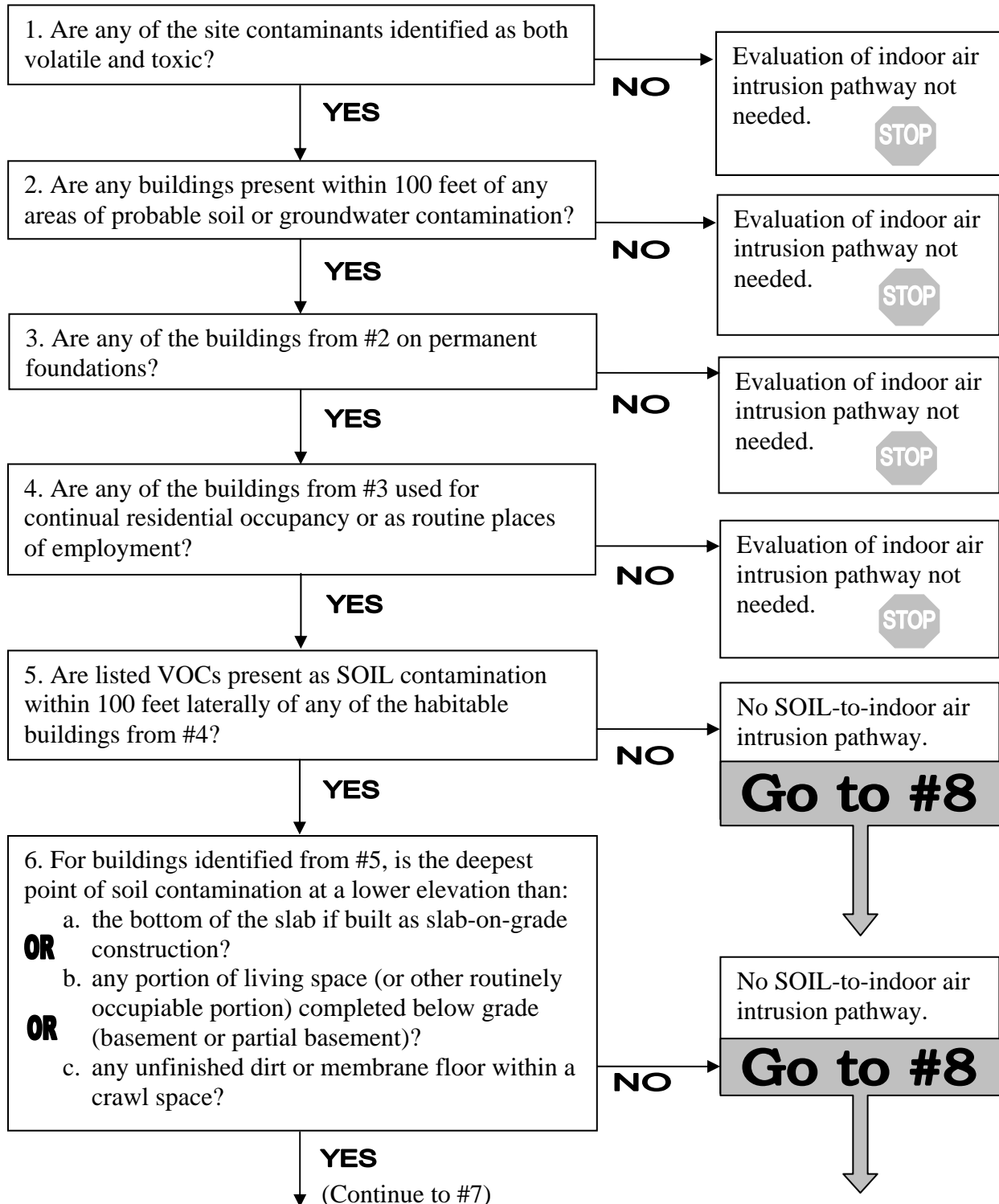
WELLS

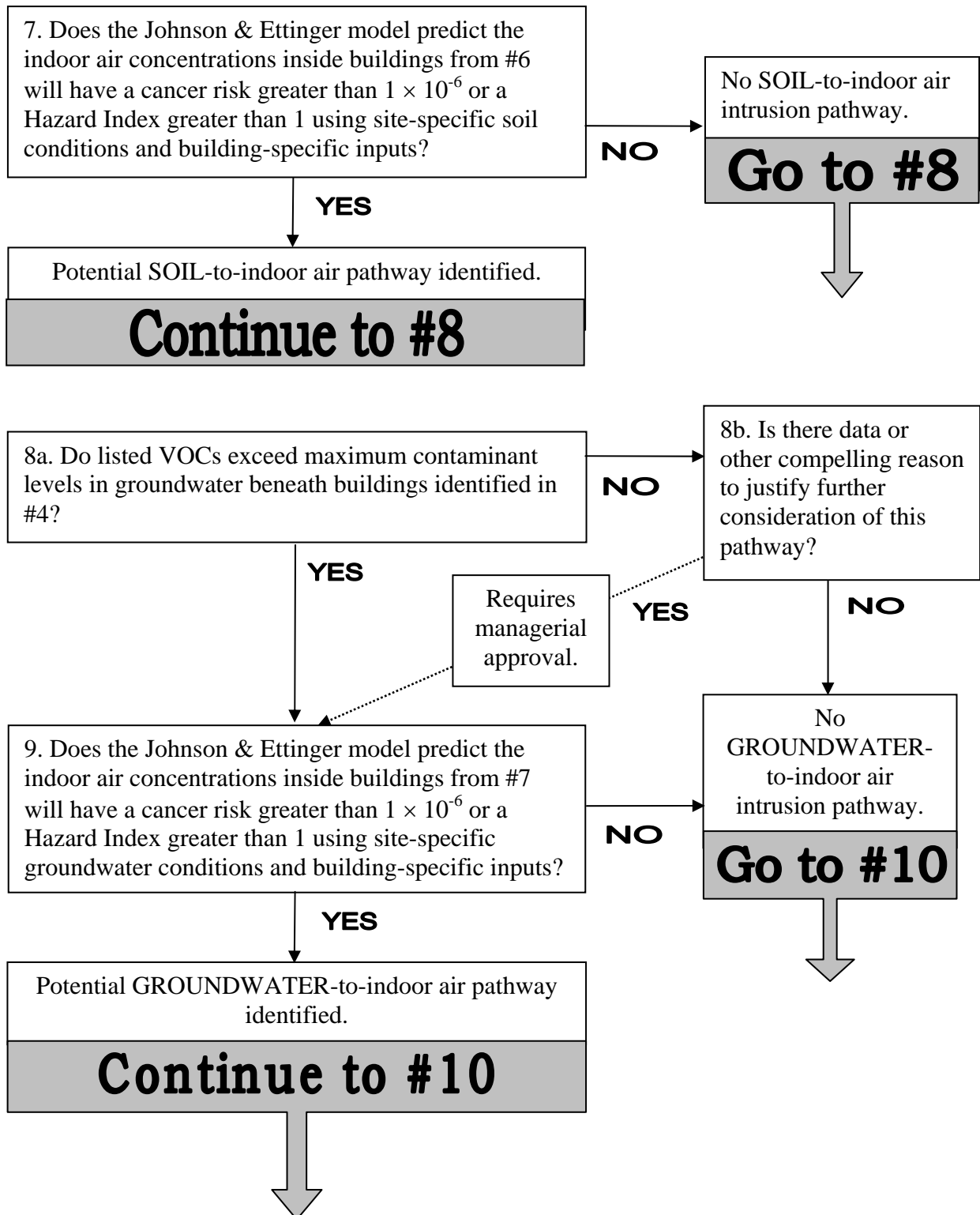
1. Is there a well on your property? NO YES
2. If yes, is the well currently in use? NO YES
3. If yes, what is the water used for?
 Drinking water Gardening Other (Specify) _____
4. If you know, indicate how deep the well is: _____ feet

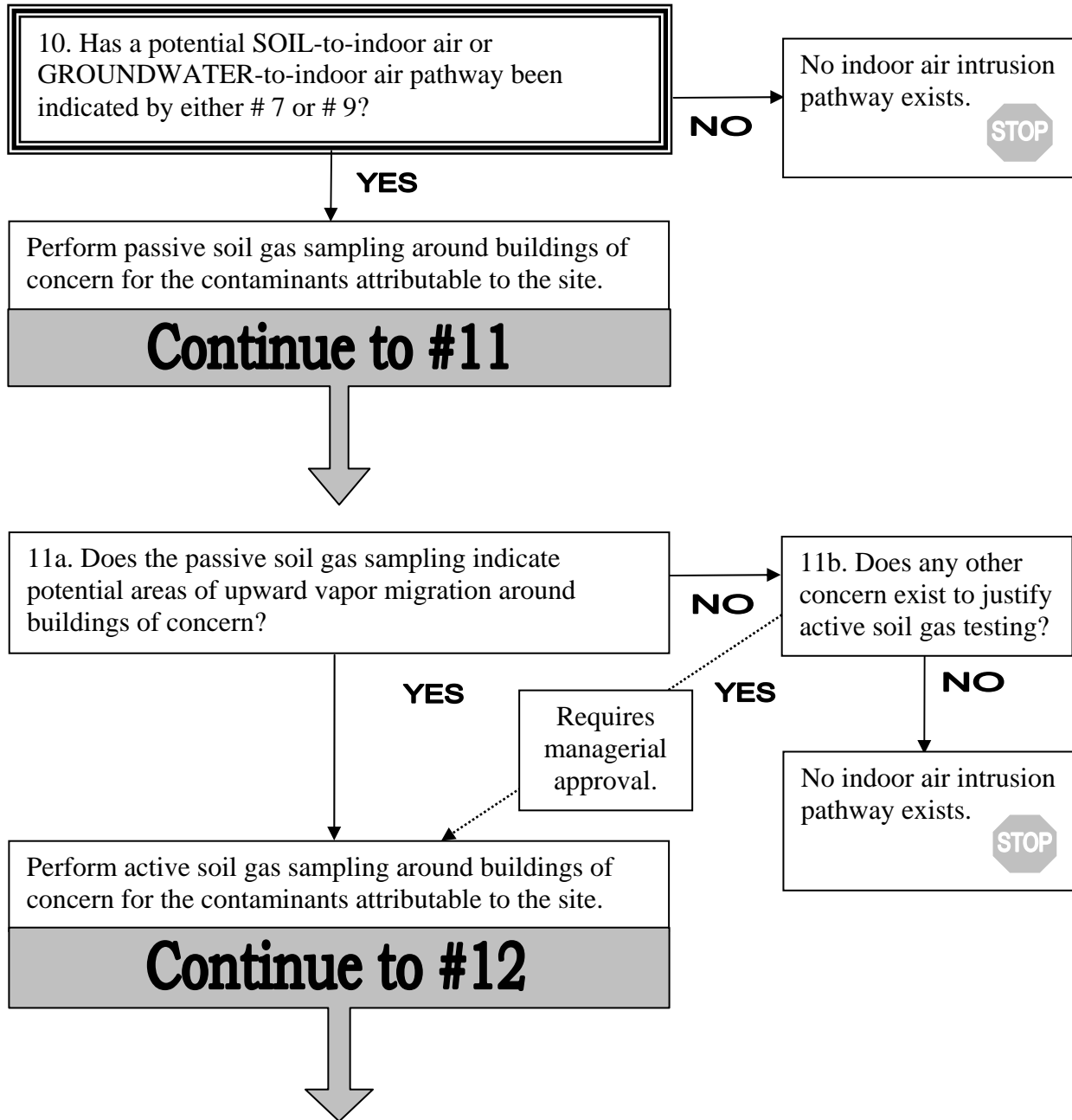
NOTES/COMMENTS: _____

5.4 South Carolina

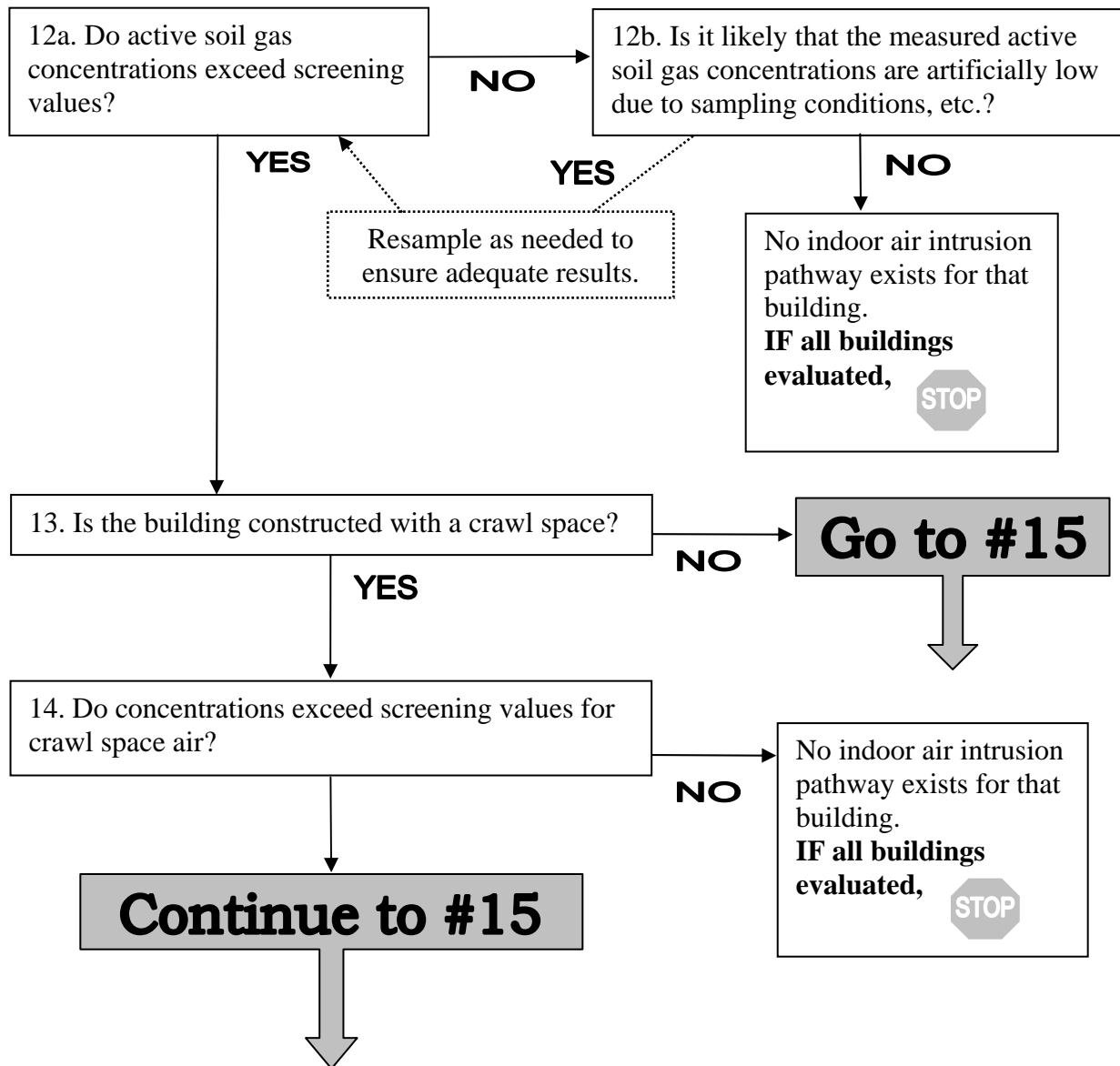
South Carolina uses a checklist and flowchart to determine vapor intrusion risks. The July 2003 version is reproduced below. The flowchart is based on the J&E model described more fully in Appendix C. Table I referenced in the flowchart is similar to that developed by EPA and displayed in Appendix B of this document.

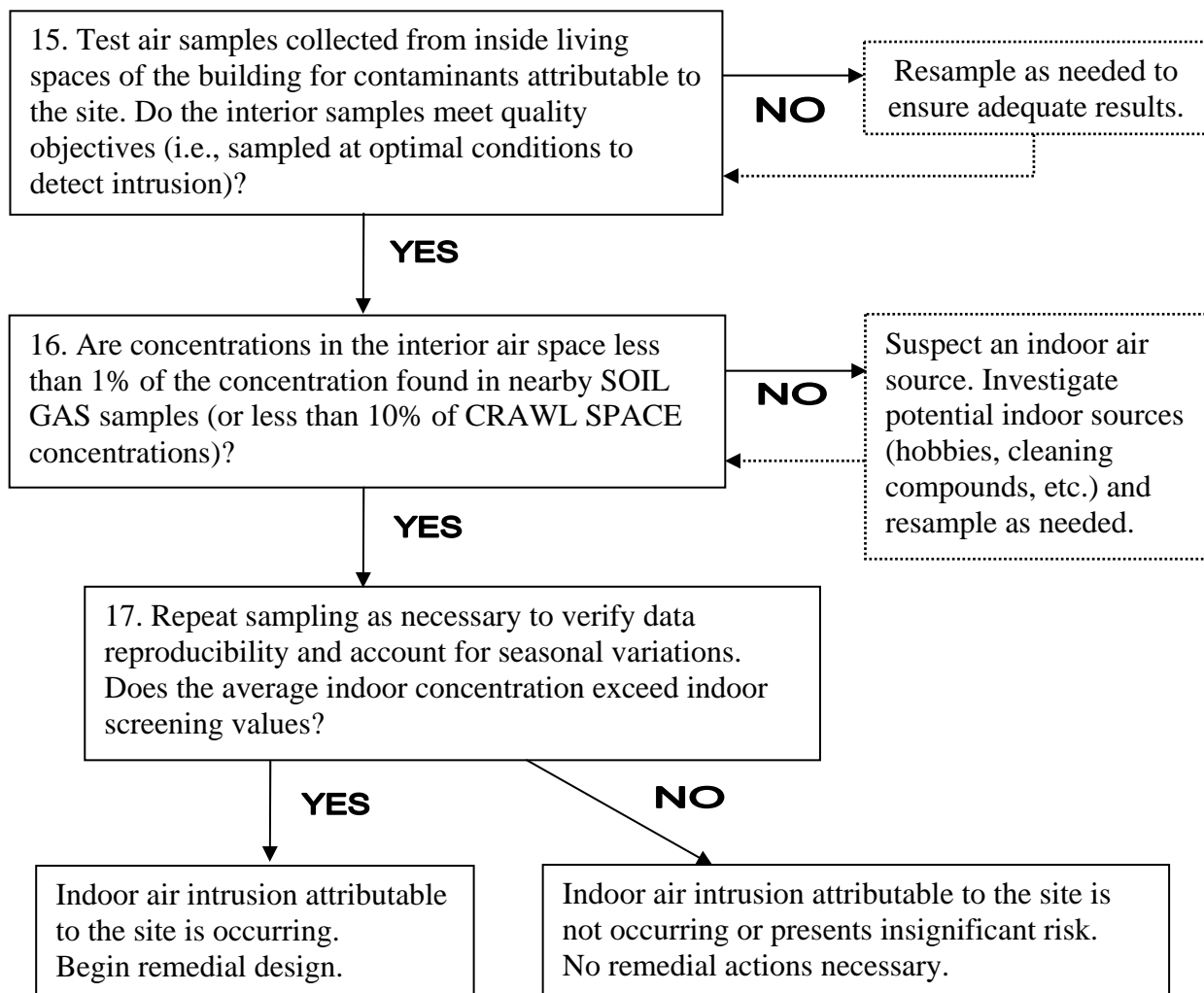






The following (12–17) should be evaluated for each building of concern.





6. FEDERAL APPROACHES TO VAPOR INTRUSION ISSUES

6.1 Review of Evolving EPA Guidance

In 1992, EPA developed a guidance document, *Assessing Potential Indoor Air Impacts for Superfund Sites*, to address vapor intrusion issues. The guidance included appendices that documented the potential for vapor intrusion as outlined in several case studies. In 1996 the EPA's Superfund Program published an EPA-modified version of one of the most popular vapor intrusion predictive models, the Johnson and Ettinger model (1991), and made it available in an easy to use spreadsheet format (EPA 1997). In 1999, EPA's Resource Conservation and Recovery Act (RCRA) Program updated guidance that was originally intended to evaluate acute indoor air conditions to require that chronic vapor intrusion exposures be evaluated at all sites requiring RCRA environmental indicator (EI) determinations. To assist evaluators and disseminate the latest understanding of the vapor intrusion issue, EPA invited state, national, and international experts to RCRA national meetings in 2000 and 2002 (slides and audio available at <http://www.clu-in.org/EIForum2000/> and <http://www.clu-in.org/EIVapor2002/>). In 2001 EPA issued draft guidance summarizing the state-of-the-science in a document that focused on

determining whether the vapor intrusion pathway for exposure was likely to be complete for defensible “human exposures under control” RCRA EI (i.e., interim) determinations (*RCRA Draft Supplemental Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway*, available at <http://www.epa.gov/epaoswer/hazwaste/ca/eis/vapor.htm#2001>). The guidance included three tiers of screening, including in its second-tier J&E model predictions using reasonably protective and scientifically defensible input parameters in precalculated graphics for varying source depths and soil types and allowed site-specific model predictions.

The need for detailed screening guidance for other cleanup programs initiated EPA’s latest vapor intrusion guidance, entitled *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (EPA 2002, available at <http://www.epa.gov/epaoswer/hazwaste/ca/eis/vapor.htm>). This draft guidance supersedes the *Draft RCRA Supplemental Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway* (December 2001). It does not supersede state guidance. However, EPA believes that states will find this guidance useful and anticipates that states will consider this draft guidance when evaluating the vapor intrusion pathway.

In noticing its availability for comment, the Federal Register stated, “The draft guidance (*Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils*) examines a single exposure pathway—the “vapor intrusion pathway.” It is intended to be a screening tool to aid users in determining whether a vapor intrusion pathway is complete and, if so, whether the completed pathway poses an unacceptable risk to human health. A complete pathway means that humans are exposed to vapors originating from site contamination. The draft guidance begins with simple and generally reasonable conservative screening approaches and gradually progresses toward a more complex assessment involving increasingly greater use of site-specific data. For those sites determined to have an incomplete vapor intrusion pathway, further consideration of the current site situation generally should not be needed. For those sites determined to have a complete pathway, guidance is provided to evaluate whether the pathway does or does not pose a potential significant risk to human health. This draft guidance is not intended to provide recommendations to delineate the extent of risk or eliminate the risk. Its sole purpose is to determine whether there is potential for an unacceptable risk. EPA generally recommends reevaluation of those sites that are screened out if site conditions or land use changes in a way that might alter a decision to screen out or other new information suggests greater conservatism is appropriate in assessing the vapor intrusion pathway.

EPA suggests that this draft guidance be used at RCRA Corrective Action, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (National Priorities List and Superfund Alternative Sites), and brownfields sites. EPA recommends that state and regional underground storage tank (UST) corrective action programs continue to use a risk-based decision-making approach as described in Office of Solid Waste and Emergency Response (OSWER) Directive 9610.17, “Use of Risk-Based Decision Making in UST Corrective Action Program,” to address this pathway at UST sites.

OSWER is currently addressing comments to this draft guidance. It is also collecting numeric data from sites across the nation (see <http://iavi.rti.org>). These data will help ensure that screening criteria are not under- or overly protective. This response may include verifying

protective attenuation factors and providing additional guidance for addressing “background” contamination. The contact for more information about vapor intrusion is Henry Schuver (shuver.henry@epa.gov).

6.2 Review of the DOE Approach to Vapor Intrusion

The Assistant Administrator for EPA’s OSWER announced EPA’s RCRA Cleanup Initiative in July 1999. As part of its RCRA Cleanup Reforms Initiation (EPA 1999, 2001), EPA identified 1,714 facilities which the agency felt were “high-priority” sites and listed in the National Corrective Action Priority System. These facilities were identified by EPA and/or states as warranting attention over the next few years because of the unacceptable exposure to pollutants and/or groundwater contamination. Furthermore, the initiative represents EPA’s comprehensive efforts to address key impediments to RCRA cleanups (i.e., RCRA corrective action), maximize program flexibility, and spur progress toward a set of national cleanup goals established under the Government Performance and Results Act (GPRA). Of these facilities, 18 are operated by the U.S. Department of Energy (DOE). The list of DOE facilities on the EPA GPRA Cleanup Baseline can be accessed online at http://www.epa.gov/epaoswer/hazwaste/ca/lists/ff_doe.pdf

As mandated by the GPRA, EPA established the following goals for 2005—95% of the Cleanup Baseline list will have “current human exposures (he) under control,” and 70% will have “groundwater migration under control.” The EPA will use two EIs*, “current human exposures under control” and “groundwater migration under control” to go beyond programmatic activity measures (i.e., reports received and approved, etc.) to track changes in the quality of the environment at the affected facilities.

It should be noted that the application of EIs is NOT a statutory or regulatory aspect of RCRA or CERCLA compliance. Rather, achieving the environmental indicator goals of “humans exposures controlled” or “groundwater migration controlled” is a method of tracking EPA’s progress in meeting the GPRA mandate. The results of the Cleanup Initiative will be reported by EPA in its GPRA report due to Congress in 2005.

A determination of “yes” with respect to “current human exposures (HE) under control” means that there are no unacceptable human exposures, including indoor air, to contamination (i.e., contaminants in concentrations in excess of appropriate risk-based levels) that can be reasonably expected under **current** land and groundwater use conditions. The “HE” EI does not consider potential future land/groundwater use conditions or ecological receptors.

A positive “migration of contaminated groundwater under control” EI determination indicates the migration of “contaminated” groundwater has stabilized and that monitoring will be conducted to confirm that contaminated groundwater remains within the original “area of contaminated groundwater” (for all groundwater “contamination” subject to RCRA corrective action at or from the identified facility [i.e., sitewide]). This EI pertains to only the physical migration of contaminated groundwater and does not substitute for other stabilization or final remedy requirements and/or expectations.

* EPA has created an “Environmental Indicators” Web site that contains EPA guidance and EI status information for private and federal facilities at <http://www.epa.gov/epaoswer/hazwaste/ca/eis.htm>.

An EI determination is to be made for an entire facility. It is anticipated that majority of the 18 DOE facilities will meet one or both of the EIs (i.e., “human exposure controlled” and “groundwater migration controlled”) by 2005.

DOE provided comments to EPA on the EPA’s draft guidance document entitled *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils: Subsurface Vapor Intrusion Guidance* (EPA 2002). The response can be accessed on DOE’s Office of Environmental Policy and Guidance Web site at <http://dewey.tis.eh.doe.gov/oepa/comments/rcra/vaporcmnts.pdf>.

7. VAPOR INTRUSION APPROACHES IN A EUROPEAN UNION COUNTRY: THE GERMAN EXAMPLE

There is little doubt among regulators in Germany that the presence of volatile contaminants in the subsoil can lead to transfer of these contaminants into buildings and potentially to hazards for residents in the buildings. However, there is considerable debate about the degree to that the evaporation of volatiles out of contaminated groundwater is relevant in this respect. At present, the basic assumptions and models and their relevance for the intrusion of volatiles are not yet identified, collected, or evaluated in Germany. According to Obernosterer and Rippen (2003), two main opinions exist:

- Diffusion of contaminants in the soil gas in the unsaturated zone is an order of magnitude faster than the contaminant transport with the groundwater. While evaporation at the ground surface takes place, this creates a steep vertical drop of contaminant concentration levels, resulting in low concentration levels near the foundations of buildings.
- The existing or planned sealing of the ground surface disturbs the diffusion intensity. In extreme cases (total sealing, no biodegradation), there would be no evaporation, resulting in balanced concentration levels of contaminants (Henry’s law) in both the soil gas and the groundwater. The balance is disturbed only by leaks in the surface sealing (cracks in slabs, etc.), which can result in diffusion or other transport mechanisms into buildings creating (potentially high) concentrations of contaminants in indoor air.

Advocates of the first opinion tend to ignore the pathway “contaminated groundwater–soil gas–indoor air–human health” (also because it is not explicitly mentioned in the relevant law, Federal Soil Protection and Contaminated Sites Ordinance, BBodSchV, see below).

To evaluate the physical parameters governing the second opinion, these parameters must be investigated. Information is collected and evaluated to determine whether abatement measures are needed. According to the present knowledge, especially the latter has not yet been tackled in a coordinated effort in Germany but will be subject to a working group of the Ingenieurtechnischer Verband Altlasten (ITVA, German Association of Remediation Experts) starting in 2003.

7.1 Overview of the Federal Soil Protection Act

The German Federal Soil Protection Act (BBodSchG) forms the legislative basis for Germany's approach to contaminated land and its management. Ratified in March 1998 and in force by March 1, 1999, the act seeks to protect and restore functions of the soil. It provides the framework to prevent harmful changes to the soil as well as to remediate the soil, contaminated sites, and water contaminated by such sites. The more technical rule specifying particular requirements of this act is the Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV).

The Federal Soil Protection Act has replaced legal requirements and standards for soil remediation that were used earlier by individual states with national uniform criteria for risk assessment and cleanup. One goal of national uniform criteria is to provide investors with consistency and legal security as well as to make it easier to calculate potential risks inherent in site cleanup and redevelopment.

7.2 Assessment, Cleanup, and Liability

Germany follows a risk-based approach to assessment and remediation. Cleanup requirements are based on intended land use and exposure conditions with threshold contaminant levels set by the federal government.

The Federal Soil Protection Act outlines risk assessment procedures and thresholds. Three levels of threshold values are identified—precautionary, trigger, and action. These threshold values are numerical values set by the government that represent different levels of contamination for different types of contamination. Each level represents a different type of regulatory response. A precautionary value is the maximum contaminant level allowed based on health and safety standards. Contamination levels higher than the precautionary level established by the government indicate the potential that a harmful change in the soil has taken place. Precautionary levels do not take future land use into consideration.

The next level of assessment, the trigger value, is based on the intended land use as well as the potential for contamination to pass from the soil to an individual, including direct contact (e.g., soil ingestion by children on a playground), contamination of plant matter, and pollution of groundwater. The act includes acceptable levels for these areas two areas (but not for soil vapor). If a trigger value is exceeded, a more in-depth assessment of the property is conducted to determine whether the property should be classified as contaminated and to determine what type of remediation measures are appropriate.

Action values represent the third risk assessment level. In general, if the action values set forth by the act are exceeded, then remediation is required. Like trigger values, action value levels are based on final intended land use and the potential for contamination to pass from soil to human. Although action level threshold values are established by law, the act states that both the assessment and the circumstances of the individual case determine the extent of remediation measures.

The Federal Soil Protection Act specifies acceptable precautionary, trigger, and action levels for different kinds of contaminants. For contaminants and environmental media not addressed by the federal government, the act (§4[5] BBodSchV) requires compound- and project-specific values to be deducted according to the specified and published rules (Bundesanzeiger 1999). These deduction rules are based on a number of research and development efforts. They include estimated and exposure scenarios that can be taken as a basis for the deduction of orienting values for soil vapor evaluation.

Federal Soil Protection Act §6 requires soil vapor investigations if there is an indication of contamination. As stated above, however, the Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) does not contain any trigger values or other criteria which could be taken for orientation while the decision is being made on potential hazard cause by soil vapor contamination and thus the necessity of indoor gas measurements. See Appendix E for more information on the German approach to vapor intrusion issues.

8. CONCLUSIONS

Vapor intrusion is an emerging issue that could have an impact on many brownfield sites throughout the country. While it is necessary to gain an understanding of the issue, it is important to note that vapor intrusion will not occur at every brownfield site. Also, even when it is determined that vapor intrusion could pose a potential risk to human health, methods exist that can minimize these risks. Planning and effective community outreach are very important when addressing vapor intrusion concerns. Guidance on vapor intrusion is evolving, and several state and federal agencies currently have guidance or are developing approaches to deal with the issue.

9. REFERENCES

- Agency for Toxic Substances and Disease Registry. 2001. *A Primer on Health Risk Communication Principles and Practices*. Washington, D.C.
- Alaska Department of Environmental Conservation. 2002. *Inhalation of Diesel Vapor in Indoor Air*. Contaminated Sites Remediation Program.
- Bundesanzeiger. 1999. *Federal Gazette No. 161a* (August 28).
- Colorado Department of Labor and Employment. 1999. *Petroleum Storage Tank Owner/Operator Guidance Document*. Denver: Division of Oil and Public Safety.
- Covello, V., and F. Allen. 1988. *Seven Cardinal Rules of Risk Communication*. Washington, D.C.: U.S. Environmental Protection Agency, Office of Policy Analysis.
- Davis, B. K., J. F. Beach, M. J. Wade, A. K. Klein, and K. Hoch. 2003. *Risk Assessment of Polychlorinated Biphenyls (PCBs) in Indoor Air*.
- DOE (U.S. Department of Energy). 1995. *Housing Characteristics 1995*. DOE/EIA-0314(93). Washington, D.C.: Energy Information Administration.

- Eaton, R. S., and A. G. Scott. 1984. “Understanding Radon Transport into Houses,” *Radiat. Prot. Dosim.* 7: 251–53.
- EPA (U.S. Environmental Protection Agency). 1986. *Guidelines for Carcinogen Risk Assessment*. EPA/630/R-00/004. Washington, D.C.: Risk Assessment Forum.
- EPA 1996a. *Soil Screening Guidance: User’s Guide*. EPA/540/R-96/018. Washington, D.C.: Office of Solid Waste and Emergency Response.
- EPA 1996b. *Soil Screening Guidance: Technical Background Document*. EPA/540/R-95/128. Washington, D.C.: Office of Solid Waste and Emergency Response.
- EPA. 1997. *User’s Guide for the Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings*. Washington, D.C.: Office of Emergency and Remedial Response.
- EPA. 1999. *RCRA Cleanup Reforms: Faster, Focused, More Flexible Cleanups*. EPA/530/F-99/018.
- EPA. 2001 *RCRA Cleanup Reforms II: Fostering Creative Solutions*. EPA/530/F-01/001.
- EPA. 2002. *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils: Subsurface Vapor Intrusion Guidance*. Washington, D.C.: Office of Solid Waste and Emergency Response.
- EPA. 2003. *User’s Guide for Evaluating Subsurface Vapor Intrusion into Buildings*. Washington, D.C.: Office of Emergency and Remedial Response.
- Eremeta, P. 2000. *Edited/Adapted Field Guideline for Protecting Residents from Inhalation Exposure to Petroleum Vapors*. Maine Department of Environmental Protection.
- Forbes, R. T. 2003. *RE: Subsurface Vapor Intrusion Guidance. Comments to Proposed OSWER Guidance*. FMC Corporation.
- GAO (U.S. General Accounting Office). 2001. *Chemical Risk Assessment: Selected Federal Agencies’ Procedures, Assumptions, and Policies*. GAO-01-810. Washington, D.C.
- GAO. 2002. *MTBE Contamination from Underground Storage Tanks, Statement of John Stephenson, Director, Natural Resources and Environment*. GAO-02-753T. Washington, D.C.
- Grimsrud, D. T., M. H. Sherman, and R. C. Sonderegger. 1983. “Calculating Infiltration: Implications for a Construction Quality Standard,” in *Proceedings of the American Society of Heating, Refrigerating and Air-conditioning Engineers Conference, Thermal Performance of Exterior Envelopes of Buildings II, Atlanta*, pp. 422–52.

- Hance, B. J., C. Chess, and P. Sandman. 1990. *Industry Risk Communication Manual: Improving Dialogue with Communities*. Boca Raton, Fla.: CRC Press/Lewis Publishers.
- Hughes, C., S. Johnson, and M. Payne. 1997. *The Evaluation and Design of the Ventilation System within Mansfield Dam (Lake Travis)*. Austin, Tex.: University of Texas at Austin.
- Johnson, P. C., and R. A. Ettinger. 1991. “Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors in Buildings,” *Environ. Sci. Technol.* **25**: 1445–52.
- Johnson, P. C. 2002. *Identification of Critical Parameters for the Johnson and Ettinger (1991) Vapor Intrusion Model*. American Petroleum Institute.
- Kamrin, M. 2001. *The Scientific Facts about the Dry-Cleaning Chemical Perc*. New York: American Council on Science and Health.
- Koonts, M. D., and H. E. Rector. 1995. *Estimations of Distributions for Residential Air Exchange Rates*. Washington, D.C.: U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics.
- Kurtz, J. P., and D. J. Folkes. 2002. “Background Concentrations of Selected Chlorinated Hydrocarbons in Residential Indoor Air,” in *Proceedings: Indoor Air 2002, 9th International Conference on Indoor Air Quality and Climate, Monterey, California, June 30–July 5*, pp. 920–25.
- Loureiro, C., L. M. Abriola, J. E. Martin, and R. G. Sextro. 1990. “Three-Dimensional Simulation of Radon Transport into Houses and Basements under Constant Negative Pressure,” *Environ. Sci. Technol.* **24**: 1338–48.
- Mann, C. S. 1999. “Indoor Air Modeling for the Palermo Well Field Superfund Site.” Memorandum prepared by Environmental Quality Management, Durham, N.C., for U.S. Environmental Protection Agency Contract 68D70002, WA No. 2-23.
- Massachusetts Department of Environmental Protection. 2002. *Indoor Air Sampling and Evaluation Guide*. Boston: Office of Research Standards.
- Michigan Department of Environmental Quality. 1998. *Risk Based Screening Levels for Soil and Groundwater Volatilization to Indoor Air*. Operational Memorandum 4, Attachment 8, Part 213. Storage Tank Division.
- Nazaroff, W. W. 1988. “Predicting the Rate of 222-Rn Entry from Soil into the Basement of a Dwelling due to Pressure-Driven Air Flow,” *Radiat. Prot. Dosim.* **24**: 199–202.
- Nebraska Department of Environmental Quality. 2002. *Risk-Based Corrective Action (RBCA) at Petroleum Release Sites: Tier 1/Tier 2 Assessments & Reports*. Lincoln, Nebr.: Leaking Underground Storage Tank/Release Assessment Section.

- New Jersey Department of Environmental Protection. 2003. *Indoor Air VOC Sampling and Analysis Requirements. Site Remediation Program*. Trenton, N.J.
- New York State Department of Environmental Conservation. 2003. *Indoor Air Sampling in Selected Structures*. Albany, N.Y.
- New York State Department of Health. 2001. *Indoor Air Sampling and Analysis Guidance*. Albany, N.Y.: Division of Environmental Health Assessment Bureau of Toxic Substance Assessment.
- NRC (National Research Council). 1983. *Risk Assessment in the Federal Government*. Washington, D.C.: National Academy Press.
- Obernosterer, I., and G. Rippen. 2003. *Verfahren gegen das Eindringen flüchtiger Schadstoffe aus Altlasten in Gebäude*. Unpublished.
- Parker, G. B., M. McSorley, and J. Harris. 1990. *The Northwest Residential Infiltration Survey: A Field Study of Ventilation in New Houses in the Pacific Northwest, Air Change Rate Air Tightness in Buildings*. Philadelphia: American Society for Testing and Materials.
- Pennsylvania Department of Environmental Protection. 2002. "Section IV.A.4. Vapor Intrusion into Buildings from Groundwater and Soil under the Act 2 Statewide Health Standard" in *Land Recycling Program Technical Guidance Manual*. Department of Land Recycling and Waste Management.
- San Francisco Bay Regional Water Quality Board. 2003. *Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater*. Oakland, Calif.
- Truesdale, R. S., M. I. Lowry, and S. N. Wolf. 2002. *Draft Procedure and Issues Report: Vapor Intrusion Pathway*. Presented to Indiana Department of Environmental Management. Research Triangle Park, N.C.: RTI International.
- U.S. Army Corps of Engineers. n.d. "Fact Sheet: Risk Assessment." Buffalo, N.Y. Accessible at <http://www.lrb.usace.army.mil/fusrap/docs/fusrap-fs-risk.pdf>.
- Washington State Department of Ecology. 2001. *Developing Air Cleanup Standards under the Model Toxics Control Act*.
- Waitz, M. F., J. Freijer, P. Kruele, and F. Swartjes. 1996. *The VOLASOIL Risk Assessment Model Based on CSOIL for Soils Contaminated with Volatile Compounds*. Report No. 715810014. Bilthoven, The Netherlands: National Institute for Public Health and the Environment.
- Wisconsin Department of Health and Family Services. 2003. *Guidance for Professionals: Chemical Vapor Intrusion and Residential Indoor Air, Guidance for Environmental Consultants and Contractors*. Madison, Wis.: Division of Public Health.

APPENDIX A

Acronyms

ACRONYMS

bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylene
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CHC	chlorinated hydrocarbon
DCE	dichloroethylene
DOE	(U.S.) Department of Energy
EI	environmental indicator
EPA	(U.S.) Environmental Protection Agency
GAO	General Accounting Office
GPRA	Government Performance and Results Act
HE	human exposure
HVAC	heating, ventilating, and air conditioning
ITRC	Interstate Technology & Regulatory Council
J&E	Johnson and Ettinger
MEW	Middlefield-Ellis-Whisman
MTCA	(State of Washington) Model Toxics Control Act
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
OSWER	(EPA) Office of Solid Waste and Emergency Response
PAH	polycyclic aromatic hydrocarbon
PCE	tetrachloroethylene (aka “perchloroethylene”)
PEL	permissible exposure level
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
SVE	soil vapor extraction
TBA	Targeted Brownfields Assessment
TCE	trichloroethylene
TOX	total organic halides
UST	underground storage tank
VOC	volatile organic compound
WAC	Washington Administrative Code

APPENDIX B

Contaminants with Sufficient Toxicity and Volatility to Be Considered Vapor Intrusion Threats

**CONTAMINANTS WITH SUFFICIENT TOXICITY AND VOLATILITY
TO BE CONSIDERED VAPOR INTRUSION THREATS
(from EPA 2002)**

CAS No.	Chemical	Is Chemical Sufficiently Toxic¹	Is Chemical Sufficiently Volatile²
83329	Acenaphthene	YES	YES
75070	Acetaldehyde	YES	YES
67641	Acetone	YES	YES
75058	Acetonitrile	YES	YES
98862	Acetophenone	YES	YES
107028	Acrolein	YES	YES
107131	Acrylonitrile	YES	YES
309002	Aldrin	YES	YES
319846	alpha-HCH (alpha-BHC)	YES	YES
62533	Aniline	YES	NO
120127	Anthracene	NO	YES
56553	Benz(a)anthracene	YES	NO
100527	Benzaldehyde	YES	YES
71432	Benzene	YES	YES
50328	Benzo(a)pyrene	YES	NO
205992	Benzo(b)fluoranthene	YES	YES
207089	Benzo(k)fluoranthene	NO	NO
65850	Benzoic Acid	NO	NO
100516	Benzyl alcohol	YES	NO
100447	Benzylchloride	YES	YES
91587	beta-Chloronaphthalene	YES	YES
319857	beta-HCH (beta-BHC)	YES	NO
92524	Biphenyl	YES	YES
111444	Bis(2-chloroethyl)ether	YES	YES
108601	Bis(2-chloroisopropyl)ether	YES	YES
117817	Bis(2-ethylhexyl)phthalate	NO	NO
542881	Bis(chloromethyl)ether	YES	YES
75274	Bromodichloromethane	YES	YES
75252	Bromoform	YES	YES
106990	1,3-Butadiene	YES	YES
71363	Butanol	YES	NO
85687	Butyl benzyl phthalate	NO	NO
86748	Carbazole	YES	NO
75150	Carbon disulfide	YES	YES
56235	Carbon tetrachloride	YES	YES
57749	Chlordane	YES	YES
126998	2-Chloro-1,3-butadiene (chloroprene)	YES	YES
108907	Chlorobenzene	YES	YES
109693	1-Chlorobutane	YES	YES
124481	Chlorodibromomethane	YES	YES
75456	Chlorodifluoromethane	YES	YES
75003	Chloroethane (ethyl chloride)	YES	YES

CAS No.	Chemical	Is Chemical Sufficiently Toxic¹	Is Chemical Sufficiently Volatile²
67663	Chloroform	YES	YES
95578	2-Chlorophenol	YES	YES
75296	2-Chloropropane	YES	YES
218019	Chrysene	YES	YES
156592	cis-1,2-Dichloroethylene	YES	YES
123739	Crotonaldehyde (2-butenal)	YES	YES
98828	Cumene	YES	YES
72548	DDD	YES	NO
72559	DDE	YES	YES
50293	DDT	YES	NO
53703	Dibenz(a,h)anthracene	YES	NO
132649	Dibenzofuran	YES	YES
96128	1,2-Dibromo-3-chloropropane	YES	YES
106934	1,2-Dibromoethane (ethylene dibromide)	YES	YES
541731	1,3-Dichlorobenzene	YES	YES
95501	1,2-Dichlorobenzene	YES	YES
106467	1,4-Dichlorobenzene	YES	YES
91941	3,3-Dichlorobenzidine	YES	NO
75718	Dichlorodifluoromethane	YES	YES
75343	1,1-Dichloroethane	YES	YES
107062	1,2-Dichloroethane	YES	YES
75354	1,1-Dichloroethylene	YES	YES
120832	2,4-Dichlorophenol	YES	NO
78875	1,2-Dichloropropane	YES	YES
542756	1,3-Dichloropropene	YES	YES
60571	Dieldrin	YES	YES
84662	Diethylphthalate	YES	NO
105679	2,4-Dimethylphenol	YES	NO
131113	Dimethylphthalate	NA	NO
84742	Di-n-butyl phthalate	NO	NO
534521	4,6-Dinitro-2-methylphenol (4,6-dinitro-	YES	NO
51285	2,4-Dinitrophenol	YES	NO
121142	2,4-Dinitrotoluene	YES	NO
606202	2,6-Dinitrotoluene	YES	NO
117840	Di-n-octyl phthalate	NO	YES
115297	Endosulfan	YES	YES
72208	Endrin	YES	NO
106898	Epichlorohydrin	YES	YES
60297	Ethyl ether	YES	YES
141786	Ethylacetate	YES	YES
100414	Ethylbenzene	YES	YES
75218	Ethylene oxide	YES	YES
97632	Ethylmethacrylate	YES	YES
206440	Fluoranthene	NO	YES
86737	Fluorene	YES	YES
110009	Furan	YES	YES
58899	gamma-HCH (Lindane)	YES	YES

CAS No.	Chemical	Is Chemical Sufficiently Toxic¹	Is Chemical Sufficiently Volatile²
76448	Heptachlor	YES	YES
1024573	Heptachlor epoxide	YES	NO
87683	Hexachloro-1,3-butadiene	YES	YES
118741	Hexachlorobenzene	YES	YES
77474	Hexachlorocyclopentadiene	YES	YES
67721	Hexachloroethane	YES	YES
110543	Hexane	YES	YES
74908	Hydrogen cyanide	YES	YES
193395	Indeno(1,2,3-cd)pyrene	NO	NO
78831	Isobutanol	YES	YES
78591	Isophorone	YES	NO
7439976	Mercury (elemental)	YES	YES
126987	Methacrylonitrile	YES	YES
72435	Methoxychlor	YES	YES
79209	Methyl acetate	YES	YES
96333	Methyl acrylate	YES	YES
74839	Methyl bromide	YES	YES
74873	Methyl chloride (chloromethane)	YES	YES
108872	Methylcyclohexane	YES	YES
74953	Methylene bromide	YES	YES
75092	Methylene chloride	YES	YES
78933	Methylethylketone (2-butanone)	YES	YES
108101	Methylisobutylketone	YES	YES
80626	Methylmethacrylate	YES	YES
91576	2-Methylnaphthalene	YES	YES
108394	3-Methylphenol (m-cresol)	YES	NO
95487	2-Methylphenol (o-cresol)	YES	NO
106455	4-Methylphenol (p-cresol)	YES	NO
99081	m-Nitrotoluene	YES	NO
1634044	MTBE	YES	YES
108383	m-Xylene	YES	YES
91203	Naphthalene	YES	YES
104518	n-Butylbenzene	YES	YES
98953	Nitrobenzene	YES	YES
100027	4-Nitrophenol	YES	NO
79469	2-Nitropropane	YES	YES
924163	N-Nitroso-di-n-butylamine	YES	YES
621647	N-Nitrosodi-n-propylamine	YES	NO
86306	N-Nitrosodiphenylamine	YES	NO
103651	n-Propylbenzene	YES	YES
88722	o-Nitrotoluene	YES	YES
95476	o-Xylene	YES	YES
106478	p-Chloroaniline	YES	NO
87865	Pentachlorophenol	YES	NO
108952	Phenol	YES	NO
99990	p-Nitrotoluene	YES	NO
106423	p-Xylene	YES	YES

CAS No.	Chemical	Is Chemical Sufficiently Toxic¹	Is Chemical Sufficiently Volatile²
129000	Pyrene	YES	YES
110861	Pyridine	YES	NO
135988	sec-Butylbenzene	YES	YES
100425	Styrene	YES	YES
98066	tert-Butylbenzene	YES	YES
630206	1,1,1,2-Tetrachloroethane	YES	YES
79345	1,1,2,2-Tetrachloroethane	YES	YES
127184	Tetrachloroethylene	YES	YES
108883	Toluene	YES	YES
8001352	Toxaphene	YES	NO
156605	trans-1,2-Dichloroethylene	YES	YES
76131	1,1,2-Trichloro-1,2,2-trifluoroethane	YES	YES
120821	1,2,4-Trichlorobenzene	YES	YES
79005	1,1,2-Trichloroethane	YES	YES
71556	1,1,1-Trichloroethane	YES	YES
79016	Trichloroethylene	YES	YES
75694	Trichlorofluoromethane	YES	YES
95954	2,4,5-Trichlorophenol	YES	NO
88062	2,4,6-Trichlorophenol	YES	NO
96184	1,2,3-Trichloropropane	YES	YES
95636	1,2,4-Trimethylbenzene	YES	YES
108678	1,3,5-Trimethylbenzene	YES	YES
108054	Vinyl acetate	YES	YES
75014	Vinyl chloride (chloroethene)	YES	YES

¹ A chemical is considered sufficiently toxic if the vapor concentration of the pure component poses an incremental lifetime cancer risk greater than 10^{-6} or a noncancer hazard index greater than 1.

² A chemical is considered sufficiently volatile if its Henry's law constant is 1×10^{-5} atm-m³/mol or greater (Johnson and Ettinger 1991).

APPENDIX C

Overview of the Johnson and Ettinger (J&E) Model

OVERVIEW OF THE JOHNSON AND ETTINGER (J&E) MODEL

The Johnson and Ettinger (J&E) model considers the transport of volatile chemicals into indoor air and calculates the expected concentration in indoor air. At a typical site undergoing evaluation with this model, key initial information is the concentration of the volatile contaminant(s) in the soil and/or groundwater at the site. This information is usually available from the sampling that accompanied initial investigation of the site.

The model first estimates the concentration of VOCs in air within the soil air space above the water table. This estimation is made using Henry's law. In the J&E model, these contaminated vapors diffuse from the source (soil and/or groundwater) until reaching a building's zone of influence. The zone of influence is the area of the soil in which moving air can transport vapors from the air space in the soil into a structure. Movement of air in this zone is caused by advection. Cracks in the building's foundation serve as entry points for these vapors; effects of wind, stack, and mechanical ventilation can all influence the rate of air intrusion from the subsurface into the basement or ground floor of the structure.

The J&E model uses information entered by the user about current or future buildings on the site. The predicted behavior of volatile organics and their ability to migrate to and through a building's foundation provide the estimated indoor air concentration. If this concentration exceeds an acceptable risk level, steps must be taken to address the source of contamination and/or provide future structures with mitigation measures to prevent excess risk due to vapor intrusion.

Sensitive Parameters and Uncertainty

There is uncertainty inherent in many of the values that are entered into any model to predict vapor intrusion. Some inputs are relatively easy to measure with a relatively high degree of confidence; others are difficult to measure and often must be estimated using professional judgment and experience. The sensitivity of the model prediction varies: small changes in some inputs may result in larger variations in the calculated indoor VOC concentrations, while other inputs may vary without significantly altering the output. The range of values, uncertainty, and sensitivity are shown on Table C-1.

The J&E model is most sensitive to input values such as the distance between the top of the contaminated soil (or groundwater) and the base of the building foundation, the concentration at the source, the permeability of the soil to vapors, the amount of residual moisture in the soil, and the difference in pressure between the building and soil. Of these parameters, the most uncertain and sensitive are the soil-building pressure differential and the residual moisture saturation in soil. Sampling methods can be devised to reduce much of the uncertainty regarding the concentration of VOCs in soil or groundwater at the source. The uncertain nature of the future buildings at the site, including air exchange rate and the permeability of the foundation to soil vapors over time, can be addressed by using appropriately conservative assumptions for the types of structures anticipated at the site (EPA 1997).

Table C-1. Uncertainty factors associated with the J&E guidelines and the associated impact on the results of the J&E model (adapted from EPA 1997)

Input parameter	Practical range of values	Default value	Relative model sensitivity	Relative model uncertainty
Soil water-filled porosity	0.02–0.43 cm ³ /cm ^{3a}	Specific to soil type*	High	High
Soil permeability	10 ⁻⁶ –10 ⁻¹² cm ^{2b, c}	Specific to soil type*	High	High
Soil/building pressure differential	0–20 Pa ^d	4 Pa ^e	High	High
Media initial concentration	User defined	NA	High	Moderate
Depth to bottom of soil contamination	User-defined	NA	High	Moderate
Depth to top of contamination	User-defined	NA	High	Low
Floor-wall seam gap	0.05–1.0 cm ^d	0.01 cm ^h	Moderate	High
Soil organic carbon fraction	0.001–0.006 ^a	0.002 ^a	Moderate	Moderate
Building air exchange rate	0.18–1.26 (h ⁻¹) ^f	0.25(h ⁻¹) ^g	Moderate	Moderate
Building volume	147–672 m ^{3h}	451 m ^{3h}	Moderate	Low
Soil total porosity	0.34–0.53 cm ³ /cm ^{3a}	Specific to soil type*	Moderate	Low
Soil dry bulk density	1.25–1.75 g/cm ^{3a}	1.5 g/cm ^{3a}	Low	Low

^a EPA 1996a and b.

^b Johnson and Ettinger 1991.

^c Nazaroff 1988.

^d Eaton and Scott 1984, Loureiro et al. 1990.

^e Loureiro et al. 1990; Grimsrud, Sherman, and Sonderegger 1983.

^f Koonts and Rector 1995.

^g EPA 2003.

^h DOE 1995.

Limitations of the Johnson and Ettinger Model

As a one-dimensional model, the J&E model does not take into account the lateral transport of vapors. It does not directly consider the possibility of preferential flow pathways such as fractures in soil and root pathways but can be modified to do so. These may all increase a building's zone of influence because they make transport of VOCs in soil easier. This larger zone of influence may enable higher concentrations to be drawn into the structure than were predicted. Once vapors arrive at the building through diffusion and convection, the process by which they

enter the building in the model is assumed to be solely the result of entry through cracks in the foundation and subsurface walls. Additional entry points are not considered, and larger than expected gaps or openings in the foundation could increase the amount of vapor intrusion beyond that predicted. Finally, the J&E model has not been extensively field-validated. The lack of experience with the model may lead to instances where the model is applied incorrectly. Other important assumptions in the J&E model are the absence of crawl spaces and the lack of active biodegradation in the subsurface (EPA 1997, Johnson 2002, EPA 2003).

APPENDIX D

Overview of the VOLASOIL Model

OVERVIEW OF THE VOLASOIL MODEL

There are other types of models that have been used to assess vapor intrusion risks. The National Institute of Public Health and the Environment of The Netherlands sponsored research that developed the VOLASOIL risk assessment model, discussed here as an example of a non-J&E risk model.

Developed by Waitz et al. (1996), the VOLASOIL model is based on another risk assessment tool, the CSOIL model, which was developed to derive action levels at soil and groundwater cleanup sites. These intervention values are based on potential risks to humans exposed to soil contaminants. The CSOIL model was designed to require site-specific measurements. VOLASOIL was developed to perform risk assessments without requiring extensive sample collection and to provide a balanced approach that was scientifically sound and easily applicable.

The VOLASOIL model can use a flexible combination of model inputs and site-specific measurements. The model can be used in specific circumstances, such as floating layers of contamination, contaminant sources below the water table, and contaminated groundwater in crawl spaces. It was important to address crawl spaces because many houses in The Netherlands have crawl spaces that are not sealed from the soil.

The VOLASOIL model contains the following assumptions (Waitz et al. 1996):

- No biological degradation
- Inexhaustible, infinite contaminant source at a certain depth in the soil
- Homogeneous soil
- No (nonequilibrium) sorption of VOCs in the open capillary zone
- No lateral transport or leaching

There are several cases associated with the VOLASOIL model. Users select the case most applicable to their site. For example, one case is used if there is contaminated groundwater in the crawl space. Another case is used if there is a very low water table. Independent calculations are made for each case that is applicable to the specific site being tested. Table D-1 lists primary and secondary data inputs for the VOLASOIL model.

Because of the flexibility of the VOLASOIL model, it may be useful for risk assessments, especially for houses that have crawl spaces. However, the model has not been used extensively in the United States. Studies may be needed to benchmark the VOLASOIL model with the J&E model before a clear understanding of the tool's applicability and any limitations to use can be evaluated.

Table D-1. VOLASOIL model primary and secondary inputs

Primary input	Secondary inputs
Ventilation rate into indoor space (m ³ /h)	Indoor space volume (m ³)
	Indoor air exchange rate with outdoor air (1/h)
Ventilation rate into crawl space (m ³ /h)	Crawl space volume (m ³)
	Crawl space air exchange rate with outdoor air (1/h)
Air flux from soil to crawl space (m ³ /m ² /h)	Building floor area (m ²)
	Crawl space height (m)
	Floor thickness (m)
	Area of one floor gap (m ²)
	Number of floor gaps in floor
	Crawl space/indoor air space pressure differential (Pa)
Vapor phase diffusion coefficient in soil air (m ² /h)	Soil moisture content (L/L)
	Soil total porosity (L/L)
	Soil vapor content (L/L)
	Henry's law constant
	Air diffusion coefficient (m ² /h)
	Water diffusion coefficient (m ² /h)
	Depth of contamination beneath crawl space (m)
Contaminant concentration in soil air (g/m ³)	Henry's law constant
	Contaminant concentration in soil water (g/m ³)

Source: Mann 1999.

APPENDIX E

Specifics of the German Approach to Vapor Intrusion

SPECIFICS OF THE GERMAN APPROACH TO VAPOR INTRUSION

Transfer Rates

It is obvious that the transfer rate of contaminants from the soil gas into buildings depends on a number of factors. The German literature on the issue calls concentration factors between 1:100 and 1:1000 realistic (Zeddel et al. 2002, see references at the end of this appendix). This transfer factor is a figure describing the dilution of the soil vapor in the indoor air. However, the exact conditions of the particular case have to be investigated, and a professional classification of the real transfer conditions has to be performed taking preferably a worst-case scenario regarding the air exchange rate and the permeability of the building structure into account. Cases where contaminated groundwater has contact to the building structure must be handled differently.

In the German literature (Zeddel et al. 2002), orientation values are derived that can be used to decide whether an indoor air contamination must be perceived and thus whether an indoor air investigation should be carried out. Based on the tolerable indoor gas concentrations threshold, values for the soil vapor concentrations are calculated back taking both the 1:100 and the 1:1000 transfer factor into account. If the soil vapor concentration is lower than the threshold corresponding to the 1:100 transfer factor, there is no evidence for the necessity for further investigations. However, measured soil vapor concentrations exceeding the threshold for the 1:1000 transfer rate are considered to be a clear indication for a substantial risk of indoor air contamination, and detailed investigations should follow. In the sense of this ITRC background document, the calculated soil vapor concentrations could indicate whether further measures (investigations, precautionary installations under newly set up buildings, etc.) are appropriate.

Modeling approaches for several settings of buildings are found in the literature (HLUG 1999). However, a number of factors influencing vapor intrusion and the indoor air concentrations cannot be modeled appropriately at a generic level because they are not constant (e.g., weather-induced pressure differences between the atmosphere, indoor air, and soil gas and their influence on concentration gradients) or depend on particular site conditions (concentration pattern in the subsoil, permeability of buildings, etc.). Table E-1 summarizes the modeled settings.

Table E-1. Results of transfer modeling (HLUG 1999)

Type of building	Situation	Transport	Transfer factor*
Industrial building	Permeable floor, good aeration	Diffusive	1:3,000
Basement room	Permeable floor, little aeration	Diffusive	1:25
Residential home	Permeable floor, medium aeration	Diffusive	1:350
Residential home	Permeable floor, medium aeration during winter heating period	Diffusive and convective	1:80
Residential home	Tight floor, very little aeration	Diffusive	1:3,500
Residential home	Cracked floor, little aeration	Diffusive	1:5,000
Residential home	Cracked floor, little aeration during winter heating period	Diffusive and convective	1:40

* The transfer factor is the relation of the maximum concentration in soil vapor versus indoor air.

Regulations for Indoor Air

Workplaces must be designed and operated in compliance with the Workplaces Ordinance (Arbeitsstätten Verordnung, or “ArbStättV”) and the Workplace Guideline (Arbeitsstättenrichtlinie, or “ASR”) as well as other regulations and provisions of occupational safety and health and to ensure the safety and health of the employees. At present, German workplaces laws are to be revised to adapt it to the Occupational Safety and Health Act, to nationally implement the European Union Workplaces Directive, and to reflect the current progress made in science and technology.

The air exchange rates that are required in the German regulations vary according to the use of the buildings and to the area of application. For example, the ASR requires an air exchange rate of 4–10 depending on the hardness of the physical labor done in the building. The technical standard DIN 4701 requires an air exchange rate of at least 0.5 for residential buildings and lists the realistic average to be between 1 in older buildings and 0.5 in modern buildings with sealed joints.

So far there is no generally applicable and binding regulation for the evaluation of contaminants in indoor air of residential buildings in the context of subsoil contamination. The quality of indoor air in industrial and commercially used buildings is strictly regulated by specified threshold values. “Maximum allowed concentration for working places (in Germany)” (Maximale Arbeitsplatzkonzentrationen, or “MAK”) are listed in TRGS 900. This list contains about 500 individual compounds with values for maximum air concentrations according to their specific effects on the health status of workers. This means implicitly, among other things, that the MAK values are not applicable for mixtures of contaminants and that they are derived based on the exposure conditions and durations of workers. Therefore, the MAK values are not applicable to evaluate indoor air results from residential buildings, but they are frequently taken for orientation purposes.

The Second Ordinance of the Federal Emission Protection Act (2. BImSchV) includes in §15(2) requirements for indoor air quality, if a technical plant is operated in the direct vicinity. The plant operator has to take special emission control measures in the plant if the air in an adjoining room contains more PCE than 0.1 mg/m³ (average value over a period of seven days), if the room is used for living or food processing.

A number of references can be found in HLUG 1999 on collections of background and reference values from various investigation campaigns in a wide spectrum of exposure patterns. Additionally, an overview on the existing guidance documents for evaluating investigation results issued by German states, Austria, and Switzerland can be found.

Soil Vapor Investigations

Appendix 1 (Nos. 2.2 and 2.4.2) of the Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV) requires that soil gas sampling be planned and carried out in compliance with the technical standard given in the VDI Guideline 3865, Sheets 1 and 2, which contain a collection of methods. In compliance with the German system of technical standards, VDI

Guideline 3865 gives a frame which may be used by experienced experts to select the particular method they consider to be appropriate in the particular case of application. For many cases, the enrichment of contaminants by drawing soil gas through an activated carbon trap is considered to be the most suitable option.

All relevant German guidelines state that soil vapor analyses may be used only for relative evaluations because the real (absolute) concentrations of contaminants in the soil gas are most likely not detected accurately. That is also the reason why there cannot be general orientation values spanning a large number of investigation cases to decide whether further investigation is necessary. Numbers derived on a toxicological basis in principle do not have any relation to the actual conditions in the field; however, they are considered necessary to explore the orders of magnitude that are of importance during decision making on the further proceeding.

Because the soil vapor concentrations are easily influenced by a large number of parameters, lots of replicate measurements and long investigation timelines are necessary to explore the actual situation in the field. During long-term field experiments, three main factors were identified to have the greatest effect on the contaminant concentration readings:

- distribution balance between soil-solids, soil-water, and soil-gas (temperature dependent);
- heterogeneity in the subsoils; and
- water content of the soil.

References

Workplaces Ordinance (Arbeitsstätten Verordnung) Accessible at <http://www.bmwi.de/textonly/Homepage/download/Arbeit/Arbeitsschutz/ArbStaettV.pdf>.

2. BImSchV (Second Ordinance of the Federal Emission Protection Act). December 10, 1990 (BGBl I S.2694), latest modification on August 21, 2001 (BGBl. I S. 2209). Accessible at <http://www.umweltdaten.de/luft/vorschriften/national/02BImSchV.pdf>.

Bundesanzeiger. 1999. *Federal Gazette No. 161a* (August 28).

Federal Soil Protection and Contaminated Sites Ordinance, (Bundes-Bodenschutz und Altlastenverordnung). Accessible at BBodSchV at <http://www.umweltbundesamt.de/altlast/web1/berichte/pdf/bbodschv-engl.pdf>.

German Federal Soil Protection Act (Bundes-Bodenschutzgesetz). Accessible in English at <http://www.bilateral-wg.org/links>.

HLUG (Hessisches Landesamt fuer Geologie). 1999. Fachliche Grundlagen zur Beurteilung von flüchtigen organischen Schadstoffen in der Bodenluft bei Altlasten. Schriftenreihe „Umweltplanung, Arbeits- und Umweltschutz,“ Vol. 263.

Obernosterer, I., and G. Rippen. 2003. „Verfahren gegen das Eindringen flüchtiger Schadstoffe aus Altlasten in Gebäude.“ Unpublished.

TRGS 900: Technical Guidance on Hazardous Substances (Technische Richtlinie Gefahrstoffe) 900 „Threshold values for Air at Working Places“ („Grenzwerte in der Luft am Arbeitsplatz, Luftgrenzwerte“). Accessible at <http://www.baua.de/prax/ags/trgs900.pdf>.

VDI Guideline 3865: Measuring Organic Soil Contaminations (01.1998) Messen organischer Bodenverunreinigungen) Verein Deutscher Ingenieure, Düsseldorf. 57 S.

- Sheet 1: Measuring high-volatile halogenated hydrocarbons, measurement plan for soil gas-testing procedures (October 1992)
- Sheet 2: Techniques for the active withdrawal of soil gas samples (January 1998)

Zeddel, A., M. Machtolf, D. Barkowski, and A. Sohr. 2002. „Leichtflüchtige Schadstoffe im Boden—orientierende Hinweise zur Bewertung von Stoffkonzentrationen in der Bodenluft beim Wirkungspfad Boden-Innenraumlufte-Mensch für Wohngebiete.“ Presented at AltlastenSpektrum.

APPENDIX F

Vapor Intrusion Case Studies

VAPOR INTRUSION CASE STUDIES

Case Study 1

Site Name: Former Healthtex Facility Brownfields Site

Location: Cowpens, South Carolina

Contaminants: Perchloroethylene, other VOCs

Contaminant Concentrations: Maximum 32 ppm (mg/L)

Site Geology: Surficial clay/silt aquifer

Distance from Contaminants to Building: Plume underlies residences

Sampling Methods: Summa canisters analyzed for VOCs by EPA Method TO-14

Building Type: Include slab-on-grade, crawl space, and basement types

Site Narrative

Previous releases of VOCs, primarily PCE, at a former textile manufacturing facility, Healthtex, Inc. in Cowpens, S.C., resulted in contamination of groundwater and surface water at the site and on adjacent residential properties. A Targeted Brownfields Assessment (TBA) of the site and surrounding properties was conducted by the South Carolina Department of Health and Environmental Control to determine the nature and extent of contamination. A separate investigation, funded exclusively by the department, focused on evaluating the potential for soil vapor and indoor air to be affected by upward migration of VOC vapors from the contaminant plume. The maximum PCE concentration detected in the groundwater plume is approximately 32 ppm. Approximately 100 residential properties overlie the groundwater contamination plume delineated by the TBA. Average depth from grade elevation to the uppermost contaminated aquifer is approximately 30 feet. Clays, silt, and interlayered silt/clay of the saprolite zone compose the vadose zone and uppermost aquifer beneath the residences. Types of construction of residences include slab-on-grade, crawl space, basement, and combinations thereof.

The soil vapor study consisted of collecting shallow (<3 feet below ground surface [bgs]) soil vapor samples beneath the exterior walls of the residences and at the crawl space entrances. Soil vapor samples were collected in Summa canisters over a 1-hour period during the summer and analyzed for VOCs by EPA Method TO-14. Approximately 40 soil vapor samples were collected. PCE concentrations in the direct-push groundwater samples that were collected within a few feet of the residences ranged 4–800 parts per billion. PCE concentrations in the soil vapor ranged from nondetect to approximately 300 $\mu\text{g}/\text{m}^3$. Due to the limited number of groundwater samples collected in close proximity to the residences, significant uncertainty exists related to the maximum concentration of PCE in the groundwater plume directly underlying the residences.

The first of two indoor air studies coincided with the soil vapor study. Both studies consisted of collecting a 24-hour Summa canister sample for EPA Method TO-14 analysis. Indoor air samples were collected at 10 residences. Residents were relocated by the department during the sampling period. The residences were selected as those most likely to be impacted by vapor intrusion based on J&E modeling. PCE was detected in one of the residences (slab-on-grade construction) at a concentration of 10 $\mu\text{g}/\text{m}^3$. PCE was not detected in the second sampling of this residence conducted in the winter. PCE concentrations detected in the soil vapor at this

residence range from nondetect to 8.73 µg/m³. Information provided by the residents on a prepared questionnaire suggested a possible association of the PCE detection in the indoor air sample with the storage of shirts laundered at a dry cleaner undergoing regulatory scrutiny of PCE containment and storage issues.

Numerous VOCs not related to either the groundwater contamination or soil vapor detections were detected in the indoor air samples. Sufficient quality assurance/quality control samples and resident responses to a preliminary questionnaire provided a basis for attributing the non-site-related VOCs to either outdoor, ambient air or indoor sources (household chemicals, building materials, etc.). Web publications made available to residents; a public availability session; and intensive, personal communication with individual residents facilitated community acceptance of the department's studies and data interpretation. Focused efforts to educate the residents about household sources of VOCs and resulting efforts by residents to mitigate these sources may have been a contributing factor in a dramatic decrease in non-plume-related VOCs evident in the results of the second, indoor air sampling.

Case Study 2

Site Name: Community of Mountain View

Location: Mountain View (San Francisco Bay Area), California

Contaminants: Trichloroethylene (TCE), *cis*-1,2 dichloroethylene, perchloroethylene (PCE), trichloroethane, other volatile organics, and fuels.

Contaminant Concentrations: 3,300 µg/L total VOCs in groundwater, TCE up to 100 µg/L in groundwater. At the Moffett Community Housing area, TCE concentrations up to 340 µg/L were detected in groundwater in 2000.

Site Geology: Soils beneath the sites are composed of fine and coarse grain deposits and alluvial material. Groundwater is hydraulically connected to portions of the deeper aquifers. Materials within the system range from clays and silts to fine and medium sands to coarse gravel. Continuous and semicontinuous aquitards divide the aquifers and aquifer zones.

Distance from Contaminants to Building: Buildings overlie areas of the groundwater plume.

Sampling Method: Hundreds of soil, soil vapor, and groundwater samples have been collected at the various facilities.

Building Type: There are a multitude of buildings varying in age and type in and surrounding the study area. New housing development is adjacent to the Moffet Field site.

Site Narrative

The Mountain View Site is composed of several contaminated sites: The Middlefield-Ellis-Whisman (MEW) Study Area that includes three EPA Superfund sites, the former GTE Government Systems, Jasco site, and the Naval Air Station Moffet Field. The land use in this area is primarily light industrial and commercial with residential areas.

Within the MEW Study Area, soil and groundwater contamination were first discovered in 1981. This led to other investigations and revealed other areas where soil and groundwater was

contaminated. Several sites were listed on the National Priorities List in 1985 and are under the oversight of state and federal agencies.

Facilities and processes that used solvents that contributed to the contamination include a manufacturer of electronic and communication equipment, semiconductor operations, and a former Naval Air Station. Solvent releases were related to leaking USTs, leaking sumps and associated piping, and poor waste management practices. Additionally, wells have acted as conduits to contaminate deeper aquifers. Recent housing developments have occurred adjacent to the former Naval Air Station.

Indoor air sampling has occurred over the past few years and included residential buildings. While detectable levels were observed in a few homes, none exceeded EPA health protective range for short-term exposure. However, when EPA anticipated a change in the TCE toxicity value, additional sampling occurred with only one home exceeding the proposed health protective range. A subslab depressurization system was installed to vent soil gas from under the home to prevent the contaminant from entering the home.

Indoor air sampling will continue adjacent to the former Naval Air station in 2003 and 2004 at the Moffett Community Housing areas. Indoor air samples will be collected from vacant housing units. Outdoor air samples will be taken at playgrounds and other common areas. Results of the sampling will provide confirmation that elevated TCE concentrations are present in indoor air and assist in identifying sources. The Navy will then develop a plan to protect long-term public health with input from state and federal regulatory agencies.

Initial cleanup involved removing the highly contaminated soil and underground tanks and sumps to remove the source. Groundwater extraction wells have been installed for plume characterization, monitoring, and extraction. Treatment is expected to take many decades to reach cleanup levels. The groundwater remedy uses slurry walls to contain the contaminants and a treatment train that included air strippers, liquid-phase granular activated carbon, and ultraviolet light treatment. In 1982, eight individual treatment facilities were in operation. Two additional regional groundwater treatment systems began operation in 1998. Two other systems operate at Moffett Field.

Public outreach has been significant at these sites. Throughout the years there are routine open house and community meetings to discuss the proposed activities and present information. A community advisory group meeting has been formed and provides a work group for people affected by the site and a forum for participating in decision-making process.

Case Study 3

Site Name: IBM Endicott Facility

Location: Endicott, New York

Contaminants: 1,1,1-Trichloroethane (methyl chloroform), TCE, and their associated breakdown products

Contaminant Concentrations: Off-site range from low parts per billion to low ppm levels

Site Geology: Unconsolidated ice contact/ice margin sands and gravels

Distance from Contaminants to Building: Plume underlies residences
Sampling Methods: Summa canisters, 24 hour-composites, EPA method TO-15 SIM
Building Type: Various types of buildings were impacted at this site

Site Narrative

At the IBM Endicott facility, in Endicott, New York, VOCs were formerly used in manufacturing operations. Groundwater contamination at the site has resulted from past accidental releases (spills and leaks) of those compounds. Although the compounds are no longer used at the facility, the contamination associated with their use remains. The primary contaminants are 1,1,1-trichloroethane (also known as “methyl chloroform”), TCE, and their breakdown products. The degree of contamination is highest in the vicinity of the manufacturing complex and diminishes with distance from the site. The contamination is transported via groundwater flow from the source areas at the facility to off-site areas southwest of the plant. Cleanup and monitoring of the groundwater contamination began in 1980 and continues today under the authority of a New York State Hazardous Waste Management Permit.

Since 1980, IBM has sought to protect the village drinking water supply by halting the spread of groundwater contamination. That process involves the use of pumping wells to capture the contaminated groundwater so it can be treated to remove the VOCs. Although groundwater data indicate that this program has been effective, it typically takes many years to clean up the groundwater. IBM is currently evaluating possible actions to expedite groundwater source containment and removal.

Since the fall of 2002, there has been an extensive effort to assess impacts associated with migration of contaminant vapors from the groundwater through the soil and into buildings in the Village of Endicott and the Town of Union. The results of the investigation indicate that vapor migration has affected the indoor air in buildings above the plume. The New York State Departments of Environmental Conservation and Health and IBM developed an action plan to cut off the vapor migration pathways. IBM implemented the agencies’ approved work plan; collecting vapor samples from within, beneath, and outside 233 buildings throughout the study area. IBM has notified affected parties of the presence, or likely presence, of vapors in building basements and has begun a program to install mitigation systems beneath the buildings where necessary. As of July 2003, IBM had identified and offered to install vapor mitigation systems at 480 properties in the Village of Endicott and the Town of Union. The mitigation systems are designed to intercept contaminant vapors before they enter the buildings. As of July 2003, more than 100 mitigation systems had been installed. The agencies estimate that 85%–95% of the buildings that need mitigation systems to intercept the IBM-related contaminants have now been identified. Those that remain to be identified are in areas where the concentrations of IBM-related contaminants in the soil gas, and in the indoor air, are low. The assessment program will continue through next year to identify all of the properties in the study area at which mitigation systems will be needed.

The community has access to a summary report table that summarizes the findings of the collection and analysis of indoor air, substructure soil vapor, and ambient (outdoor) air at selected structures. It is organized by the core sampling event with multiple additional sampling

phases. The summary report table and figures summarizing the sample collection and results were submitted to the NYSDEC by IBM and can be viewed at www.dec.state.ny.us/website/dshm/sldwaste/indicottsamplng.htm.

Case Study 4

Site Name: City-Rail Rhein-Ruhr – Sect. Duisburg – Subsect. 9 – Meiderich N.

Location: City of Duisburg, State of Nordrhein-Westfalen, Germany

Contaminants: Benzene, toluene, ethylbenzene, and xylene (BTEX) and polycyclic aromatic hydrocarbons (PAHs)

Contaminant Concentrations: 10 mg/L each for BTEX and PAHs

Site Geology: See Table F-1

Distance from Contaminants to Building: Downtown area, contaminated groundwater in a depth of 2–5 meters below grade, subway line to be built in the saturated zone

Sampling Methods: In-liner drillings, groundwater sampling

Building Type: Subway tunnel pipes, 1.3 km long, 0–15 m deep.

Table F-1. City-Rail Rhein-Ruhr site geology

Formation	Layer	Lithology	Thickness	Extension
Quaternary	Fill	Soils with varying portions of ashes, debris, and slags	1–4 m, 2-m mean	Wide in the entire area
	Flood clay	Sandy clayey loam	0–2 m	Locally
	Lower terrace/Lower midterrace of the Rhine	Sand and gravels	5–15 m	Wide in the entire area
Tertiary	Ratingen clay	Silty limey clay with single lime-marl-stone layers	0–3 m	Locally only in the southern half of the site
	Walsum sea sand	Silty fine sand	2–15 m	Diminishing in the northern half of the site
	Hamborn clay	Sandy silty clay	1–5 m	
	Hamborn fine sand	Silty fine-sand	3–11 m	

Site Narrative

The projected subway tunnels are located perpendicular to the direction of the groundwater flow downstream of a former process plant for coal tar. The plants site itself is heavily contaminated with tar oils creating a contaminated groundwater plume. PAHs and BTEX have shown to be suitable guiding analytical parameters during the investigation of the site. Results of earlier investigations indicate that the contamination of the subsoils and the groundwater is extending into the area of the projected subway line. Site geology is summarized in Table F-1.

The tunnels at the site will be created by using a large-scale driller with hydroshielding of the front area of the newly created tunnel and installation of the tubing using this shield coat. The tubing is composed of prefabricated concrete parts that will be assembled to form the tunnel walls. Teflon fittings will be used to seal the joints between the parts.

One of the key-parts of the ongoing planning activities is the testing of the long-term stability of the materials (concrete tubing, joint fittings, support liquid of the hydrosshield) when getting in contact with the contaminants present in the soil, dissolved in the groundwater or as free phase. To avoid diffusion transfer of volatile compounds into the tunnel during construction and operation, various concrete mixtures are tested for their sealing properties. Toxicological risk assessments of the expected contaminant concentration levels in emissions and emissions during construction and operation are carried out.

Case Study 5

Site Name: Former Steam-Cleaning Facility Fuerstinnenstrasse

Location: Gelsenkirchen, State of Nordrhein-Westfalen, Germany

Contaminants: PCE

Contaminant Concentrations: Soil: Maximum value: 1400 mg PCE/kg dry soil, mean of 14 readings: 157.4 mg PCE/kg, groundwater 4 mg PCE/L maximum

Site Geology: Sand and gravel layers (see site narrative for additional details)

Distance from Contaminants to Building: A few meters (downtown area)

Sampling Methods: Drillings, auger drillings, groundwater sampling, soil vapor sampling, ambient air sampling: active and passive adsorption

Building Type: Two-story homes with basement underneath

Site Narrative

From before 1897 until 1974 a laundry was operated on the site. Later, the facility was extended with a dry cleaners unit. After shutdown of the facility in 1985/1986, two row-housing units with small gardens were set up in the northern part of the site. During excavation for the construction, chlorinated solvent contamination was found in the soil vapor and groundwater. Investigation showed elevated levels of mainly PCE. The extent of the groundwater contamination required remedial measures.

The subsoil at the site consisted of the following layers:

- Layer 1 (fill): The upper fill layer consists mainly of sand-gravel mixtures and soils of varying grain sizes blended with building debris. The thickness of the layer is in average approximately 1.6–2.9 m.
- Layer 2 (Quaternary): The quaternary layers (the lower terrace sediments of the river Emscher) that are underlying the fill are present in the by far widest parts of the site. In some areas the fill material has displaced the sediments. This creates a gap in the Quaternary layer. The terrace sediments are mainly fine sandy silts with varying portions of clay and sand. Locally there can some organic portions be present.
- Layer 3 (Emscher-marl): Solid marlstones, which are weathering to a clayey to fine sandy silt in the upper portion of the layer. The unweathered marlstone is a fractured aquifer. The buildings on the site were set up on the unweathered marlstone after digging out its

weathered upper portion. The upper limit of the Emscher marl has an average elevation of 2.9 m below grade ranging 1.9–4.5 m bgs.

The remedial design for the site included an excavation of the hotspots in the Quaternary layer and the Emscher-marl and a subsequent groundwater treatment. The presence of contaminants in the ambient air of the basements was determined after active sampling for halogenated VOCs and BTEX using adsorption samplers. Also, passive diffusion samplers were used to acquire samples for gas chromatograph screening analyses. The results showed PCE concentrations of up to 1.38 mg/m³ ambient air. It is not clear yet whether the contaminants migrated through the walls or entered the basements through the pipe holes in the walls.

To protect the residents and to allow unlimited use of the basements, a soil vapor extraction (SVE) system and a leachate extraction unit were installed. The latter instrument was installed in the hot-spot area for use when the area water table was elevated. The SVE system was designed reduce the contamination in the remediation area around the homes to prevent transport by diffusion or other mechanisms into the homes. The specification of the targeted contaminant concentration levels in the ambient air is based on the 2nd Federal Emission Protection Ordinance (December 10, 1990 [BGBL I S.2694], latest modification on August 21, 2001 [BGBL I S. 2209]) and is the reduction to 0.1 mg/m³ in ambient of the rooms. It should be noted that the SVE system and the other remedial measures were not designed primarily to reduce the contaminant concentration levels in the soil.

Case Study 6

Site Name: Former Fur-Factory Fuldataal

Location: City of Fuldataal, State of Hessen, Germany

Contaminants: Tetrachloroethane, TCE, tetrachloromethane

Contaminant Concentrations: Total chlorinated hydrocarbons (CHC): 20,000 µg/L maximum in groundwater, 20,000 mg/m³ maximum in soil vapor, and 1,000–13,000 µg/m³ in indoor air in residential buildings before remediation

Site Geology: See Table F-2

Distance from Contaminants to Building: 10 m minimal distance from spill

Sampling Methods: No information

Building Type: Private homes with basement underneath

Site Narrative

In the former fur-processing plant Fuldataal, chlorinated solvents had been used for degreasing purposes. Significant spillages over the time of operation caused a CHC plume in the groundwater that reaches about 650 m in lateral distance and covers an area of about 1.5 km². Soil gas was found to be contaminated in an area of about 30,000 m². The former sewage system on the site and the leaks in it are considered to have contributed substantially to this wide spread of contaminants.

The site is located in the outer rim of a water reserve area in a part of town where residential housing and some businesses are located. The plume is drifting in north-northwestern direction

towards fish ponds located in the vicinity. The contamination is threatening the main aquifer, which has regional importance; the water table is in a depth of about 45 m bgs. Site geology is summarized in Table F-2.

Table F-2. Former Fur-Factory Fuldata site geology

Formation	Lithology	Thickness
Quaternary	Loam	2–5 m
Tertiary	Fine sand	3–5 m
	Lignite	0.1–0.5 m
Upper Buntsandstein	Clay-silt-stone	>30 m

The lignite lies in a depth of 4–6 m bgs and is embedded in the Tertiary sand layers. These sand layers are aquifers. Stratum water can be found occasionally within the Quaternary layers; in dry months the stratum water layers may be found completely dry. The groundwater table is about 5–7 m bgs; seasonal ranging in height is about 1–1.5 m.

Because of the high readings during indoor air measurements, immediate action was taken by installing SVE wells down to the depth of the basement slabs of the homes and linking them to a total of four SVE systems, which have operated since then. These measures created almost contamination-free zones underneath and surrounding the buildings. Indoor air CHC concentration levels have dropped from 1,000–13,000 $\mu\text{g}/\text{m}^3$ to <40–100 $\mu\text{g}/\text{m}^3$. Only one building still has higher readings (40–250 $\mu\text{g}/\text{m}^3$ total CHC), which can be explained (in part) by the unpaved floor in that particular basement and a relatively open building structure, resulting in a chimney effect inside the house.

For groundwater remediation purposes, five extraction wells were installed in 2002, and two drainage pipes each 250 m long and about 5–7 m deep were constructed perpendicular to the groundwater flow. The extraction wells are located in the center of the spill and will be used for hot-spot pumping, whereas the drainage pipes shall catch the groundwater downstream and thus protect the main aquifer and the fishponds. The main advantage of the drainage pipes is the extremely low operational cost because only minimal pumping is required to control a large lateral downstream width.

The extracted groundwater is treated by carbon adsorption and is completely reinfiltreated using horizontal infiltration wells and the fish ponds. The duration of the groundwater remediation is estimated to be about 10–20 years.

SVE and treatment are planned to start in August 2003 and are estimated to last about 4–6 years. It will require the relocation of the aboveground systems a number of times because of the wide area that must be covered (30,000 m^2). After the remedial activities, the former fur plant site is dedicated to be a residential area.

Case Study 7

Site Name: Drycleaners Wallstrasse

Location: City of Kassel, State of Hessen, Germany

Contaminants: PCE, TCE, DCE, vinyl chloride

Contaminant Concentrations: Total CHC: 100,000 µg/L maximum in groundwater near ground surface; 10,000 µg/L maximum in deeper groundwater; 2,000 mg/m³ maximum in soil vapor; and up to 10 mg/m³ in basement indoor air and up to 1 mg/m³ in the living rooms of the residential buildings prior to remediation

Site Geology: See Table F-3

Distance from Contaminants to Building: The building foundations are directly set into the contamination

Sampling Methods: No information

Building Type: Multistory apartment buildings with basements underneath

Site Narrative

The site used to be part of the medieval fortification of the city of Kassel. The trench of the fortification was graded with fill some centuries ago after having been grown over with reeds and being filled with sediments. At the surface, there are no remnants of the fortification to be seen anymore, but the subsoil structures of the town wall and the trench have a significant influence on the groundwater hydraulics. In the mid 1900s, a large dry cleaning facility of the German army was set up at the site. After demolition of the facility in the 1970s, residential apartment units were set up on the site, which is today a completely residential community. Site geology is summarized in Table F-3.

Table F-3. Drycleaners Wallstrasse site geology

Formation	Lithology	Thickness
Quaternary	Silt and clay	2–6 m
	Sand-gravel, silty	2–7 m
Upper Buntsandstein	Clay-silt-stone	>30 m

The upper aquifer is in the Quaternary gravel layers on top of the clay formation. The water table of the groundwater is not free in the area of the former trench and is 3–4 m bgs. A dam that elevates the water table in the nearby river Fulda has an additional influence on the hydraulic conditions on the site. Fortunately, the location of the contamination in the former trench causes stable conditions; the plume is not moving off site.

During operation of the dry cleaners, chlorinated solvents were spilled into the subsoil both via the sewage system that collected the runoff and let it infiltrate through leaks in the pipes and at various locations all over the former operational area. The foundations of apartment buildings are in direct contact with the contamination, and the volatile CHCs intruded the buildings via the sewage and supply piping system.

The high readings of indoor air measurements induced immediate action in 1995—installing an SVE system and drawing the contaminated soil vapor from underneath and the surroundings of the buildings. To extend the unsaturated zone, groundwater extraction with subsequent desorption-treatment is applied. The measures were effective in removing the contamination and thus reducing the diffusion into the basements drastically. The measures taken have extracted

about 4 metric tons of contaminants from the subsoil so far. The indoor air has been monitored on a regular basis in the relevant buildings since 1994.

So far there is no generally applicable and binding regulation for the evaluation of volatile CHC readings in indoor air. In this particular case, the responsible authorities, the Environmental Department of the District Government of Kassel (Staatliches Umweltamt der Regierungspräsidiums Kassel) has specified a trigger value, and a toxicological risk assessment was carried out to evaluate the hazard that might be posed by the single compounds. The specification of the trigger value was calculated using an empirical background value that is considered to be the average for the indoor air in residential living rooms in Germany. This value was determined to be 0.041 mg/m³. If the trigger value of 0.04 mg/m³ is exceeded, further investigations for continuous monitoring have to be carried out.

The SVE measures explained above found living room air concentrations of below 0.04 mg/m³. Air monitoring efforts are continuing at the site. The toxicological risk assessment revealed an action value of 5 mg/m³ total volatile CHC, mainly based on the toxicological data for TCE and PCE, which are the best known substances in the mixture of contaminants. If the action value is exceeded, safeguarding measures have to be taken. To further lower cancer risk and avoid other effects of long-term exposure, the toxicological study stated that a volatile CHC concentration of 1 mg/m³ indoor air should be the remedial goal. With this value, also the concentrations of stronger toxic compounds like trichloromethane and tetrachloromethane should be safely kept below an effect level, which would be in this example by a factor 100–500 below the maximum allowed concentration for working places in Germany (Maximale Arbeitsplatzkonzentrationen).

The remedial actions are carried out by the District Government Kassel, funded by the state of Hessen, and managed by the HIM GmbH, the project management body for public remedial activities in Hessen and its consultants.

Case Study 8

Site Name: Chemical Trade Kassel

Location: City of Kassel, State of Hessen, Germany

Contaminants: Volatile CHC, chlorobenzene, other halogenated organics measured as total organic halides (TOX)

Contaminant Concentrations: Total CHC 500,000 µg/L maximum in groundwater, chlorobenzene up to 3,000 µg/L maximum in groundwater, TOX 300,000 µg/L maximum in groundwater

Site Geology: See Table F-4

Distance from Contaminants to Building: Minimum distance between residential homes and the spill site is 30 m

Sampling Methods: No information

Building Type: Private homes with basements underneath

Site Narrative

The site was formerly used by a small chemicals trading company that repackaged and blended various chlorinated solvents. Today, the buildings are demolished, the site is vacant, and the surrounding is a purely residential area. Site geology is summarized in Table F-4.

Table F-4. Chemical Trade Kassel site geology

Formation	Lithology	Thickness
Quaternary	Clayey sandy silt	3–12 m
Tertiary	Sand–gravel, clayey, silty	0.5–1.5 m
Upper Buntsandstein	Clay-silt-stone	>30 m

The Tertiary gravel and sand layers are the aquifers, which locally can include extremely clayey aquitard layers. The water table of the groundwater is not free in the area of the former spill site and is to be found at a depth of 3–5 m bgs. About 300 m downstream the water table is only 1–3 m bgs. The seasonal variation of the water table height is significant (about 1–3 m).

The contamination has created a plume of about 60,000 m². A larger number of privately owned parcels are affected by the contaminated groundwater flow off the site. In some of the homes, indoor air readings of up to 194 µg/m³ total volatile CHC were measured.

In the years 1998 and 1999 about 12,000 metric tons of contaminated soil was excavated from the hot-spot area down to a depth of about 12 m. A portion of the excavation material was treated on site using a thermal desorption unit and was filled back into the excavation pit after treatment.

The groundwater remediation was prepared after the soil excavation by installing horizontal wells, a drainage system, and some vertical wells for extraction of the groundwater. The groundwater remediation covers an area of about 100 m downstream of the spillage site. Residual concentrations in the unsaturated zone were removed by using an SVE system. The house that was affected most heavily by the intrusion of contaminated vapors was remediated by installing an SVE system that allows for continuous operation. The system has proven to effectively protect the indoor air in that house.

Prior to start-up of the groundwater pumping, the consolidation characteristics of the soil were tested to avoid damage to the building structures induced by the lowering of the groundwater table. Modelling results showed that a lowering for 3 m maximum was considered to be safe. Due to the sensitive conditions of this site, a continuous monitoring of the levels of the water tables is carried out. The real consolidation of the buildings is monitored in two-month intervals.

Because the contaminated groundwater plume moves under several residential buildings, indoor air monitoring is done during the remedial activities. A “background value for average German households” of 40 µg total volatile CHC per m³ indoor air is used to evaluate monitoring results. If the value is exceeded, it has to be investigated whether the contamination in the subsoil is the reason or other sources of volatiles in the household caused the elevated readings. In case of significant intrusion from the subsoil, safeguarding measures would have to be taken.

The fate and transport of the contaminants with the groundwater and relative to the groundwater were further investigated. First results show that the contaminants—which have a higher specific weight than water—may be transported to the upper part of the groundwater body by capillary rise. These results were achieved by sampling and analyzing the water in garden wells that reach down to only the capillary fringe of the aquifer. Further investigations will start soon and will comprise installation of sampling wells into the capillary fringe right next to already existing wells that reach deeper down into the main part of the aquifer. Comparative investigations of the groundwater and the capillary water are considered to give better indications on the distribution of the contaminants and thus of the risk for vapor intrusion in the homes above the plume.

The remedial actions are carried out by the State of Hessen and are managed by the HIM GmbH, the project management body for public remedial activities in Hessen and its consultants.

APPENDIX G

ITRC Contacts, Fact Sheet, and Product List

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