GRADIENT
TRENDS
Risk Science & Application

Winter 2004

Vapor Intrusion – An Overview

Recent interest in the vapor intrusion pathway is leading to a variety of public and regulatory reactions at waste sites.

Vapors emanating from contaminated soil and/or groundwater, and subsequent infiltration of such vapors into buildings (referred to as vapor intrusion), has become a hotly debated issue in the last few years. The U.S. EPA's recently published toxicity reassessment for trichloroethylene (TCE) and concerns regarding the reliability of indoor air concentrations predicted by the commonly used Johnson and Ettinger (1991) model are among the key issues driving this debate. Using the upper-bound cancer slope factor for TCE (which is being used without much thought to its appropriateness for a particular exposure scenario – see related article) together with the EPA-recommended default input values for the Johnson and Ettinger model, can result in a risk-based groundwater cleanup goal for TCE that is less than its drinking water Maximum Contaminant Level (MCL). Consequently, sites with TCE contamination are receiving significant attention from regulators. The EPA is re-evaluating TCE sites where remedial actions have already been implemented (Richtel, 2003). In California, previously issued Records of Decision (RODs) at TCE sites are now being reopened to examine this issue. Adding to this concern, recent indoor air quality data (most notably related to a groundwater plume in Denver, CO) have suggested that in some instances (certain site conditions and chemicals) the Johnson and Ettinger model may under-predict indoor air concentrations.

Vapor intrusion can be an important consideration when volatile organic compounds (VOCs) are present in the subsurface, typically groundwater, near an occupied building.

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I N S I D E

Letter to our Readers

January 2004

Dear Colleague,

Chlorinated solvent plumes and the potential for vapor intrusion into indoor air has recently captured attention in the environmental community – attention that has been heightened by the U.S. EPA's proposed new toxicity factors for trichloroethylene (TCE). The proposed toxicity of TCE suggests the potential for unacceptable risk at concentrations currently considered to be within background, opening up questions about how best to proceed in ongoing assessments. This issue of *Trends* considers the latest information on chlorinated solvents toxicity, measurement, and remediation.

Contributors to this issue include Mr. Manu Sharma, Gradient Principal and groundwater modeling expert, Dr. Lorenz Rhomberg, Gradient Principal and specialist in quantitative risk assessment, and Ms. Tina Souza, a risk assessor with significant experience with the Johnson and Ettinger model used to evaluate the potential for indoor air impacts from groundwater plumes. Joining them in our guest column is Mr. John Vidumsky, of the Bioremediation of Chlorinated Solvents Consortium of the Remediation Technologies Development Forum, who gives us his perspective on new understandings of remediation of chlorinated solvent plumes.

We hope this issue of *Trends* will provide you with new insights on the current status of risk and remediation of chlorinated solvent plumes.

Yours truly,

Neil Shifrin, Ph.D.
President

Trends is a free publication of Gradient Corporation, a national leader in risk assessment and negotiation of risk-based remediation. If you have a colleague who would benefit from this publication, please contact Bonnie M. Johnson at (617) 395-5000 or email us at *trends@gradientcorp.com.*

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Vapor Intrusion – An Overview

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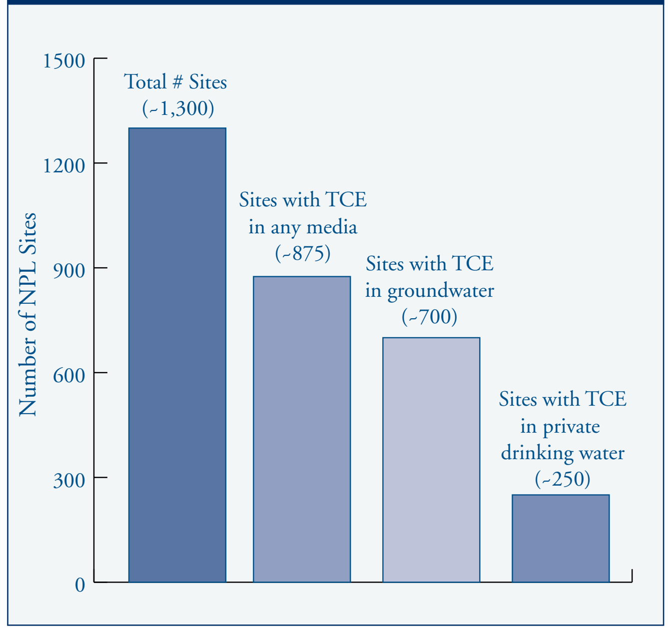
Occurrence of Trichloroethylene (TCE) at National Priority List (NPL) Sites



Source: Agency for Toxic Substances and Disease Registry. Internet HazDat. Database updated January 2003.

Vapor intrusion can be an important consideration when volatile organic compounds (VOCs) are present in the subsurface, typically groundwater, near an occupied building. If a building is constructed over VOC-affected soils, or if an underground storage tank beneath a building leaks, then soils can also act as a source of vapors. Environmental agencies have established numeric criteria, such as depth to water table and distance of groundwater contamination from an occupied building, that define when vapor intrusion needs to be considered in remedial decision-making. For example, the EPA (U.S. EPA, 2002) requires that vapor intrusion effects be considered if a VOC plume is less than 100 feet from an occupied building; states have established their own criteria.

Indoor air concentrations resulting from vapor intrusion can either be measured or modeled. However, both approaches pose their own unique set of challenges (see related article). Measurements are prone to interferences from background sources including numerous consumer and household products (*e.g.*, carpets, cleaners, paints) that emit VOCs. Another measurement challenge is that air analytical techniques are sometimes insufficient to measure levels as low as the health-based target air concentrations. Modeling to simulate site-specific conditions can be data intensive and sometimes not accepted by regulators unless the EPA-recommended default model input values are used. The choice of the evaluation approach – measure *vs.* model – is a case-specific decision.

In addition to sites with TCE, the increased focus on vapor intrusion related risks is expected to have a major impact on Resource Conservation and Recovery Act (RCRA) facilities attempting to demonstrate compliance with the "Corrective Action 725" Environmental Indicator (U.S. EPA, 2002). This program requires that human exposures be controlled to acceptable levels by 2005. Risks *via* vapor intrusion are a key component of this evaluation and have led to the EPA's issuing a number of related guidance documents (Johnson *et. al.*, 2001 and U.S. EPA, 2002).

The choice of an appropriate risk management threshold or target also has a significant implication on remedial decision making. For example, at an active industrial facility, either OSHA-promulgated occupational permissible exposure limits (PELs) or risk-based concentrations back-calculated using a risk threshold (typically incremental cancer risk of one in a million) could be used to define target indoor air concentrations – an issue brought to a head by the RCRA Environmental Indicator program. After substantial deliberation, OSHA and the EPA have agreed that OSHA regulations would apply in occupational settings (U.S. EPA, 2002). However, this does not apply to Superfund sites, where cleanup levels are to be set using the EPA's target risk approach while being consistent with applicable relevant and appropriate requirements (ARARs). The two approaches can yield very different results.

Overall, vapor intrusion can be an important exposure pathway at sites with VOCs in groundwater and, in certain limited instances, in soils. However, the recent attention focused on this subject, especially by the media, has created an inappropriate public notion of perceived significant human health risks, where none might exist. Although evaluation of vapor intrusion risks can be a complex issue, careful consideration of site conditions and proper application of the available analytical tools can readily bound the problem and lead to sound remedial decisions.

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Johnson, P.C. and R.A. Ettinger. 1991. Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings. *Environ. Sci. Technol.* 25(8):1445-1452.

Johnson, P.C., T.A. McAlary, and I. Hers. 2001. Supplemental Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway (Vapor Intrusion Guidance). October 2001. Accessed on-line November 2003 at http://www.epa.gov/correctiveaction/eis/vapor/vapor.pdf.

Richtel, M. 2003. EPA Takes a Second Look at Many Superfund Sites. *The New York Times*, January 31, 2003.

U.S. EPA. 2002. Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway From Groundwater and Soils (Subsurface Vapor Intrusion Guidance). Accessed on-line November 2003 at http://www.epa.gov/correctiveaction/eis/vapor/guidance.pdf.

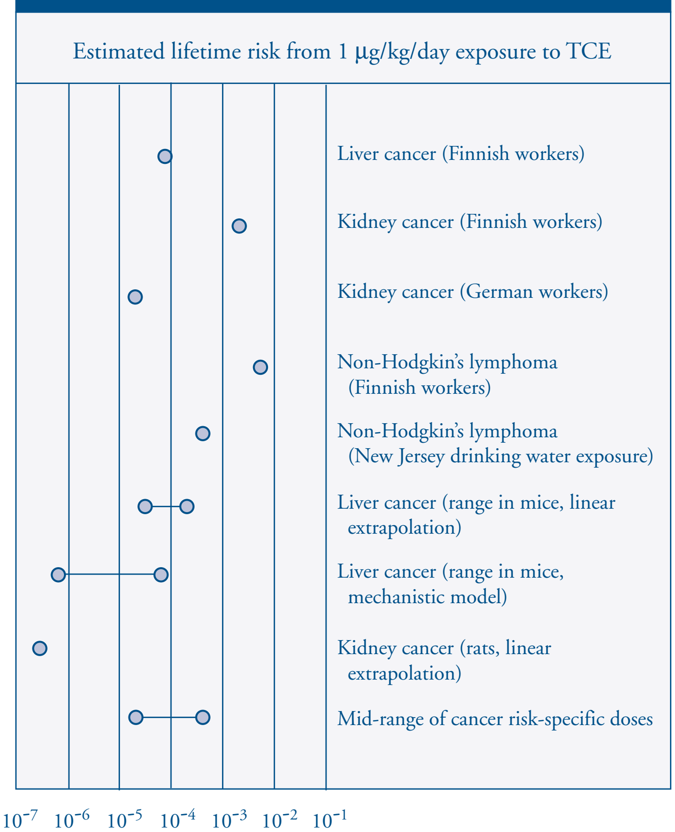
Turmoil about TCE: The EPA's Controversial Reassessment of Cancer Risks

The U.S. EPA's draft reassessment of TCE potency is leading to a variety of interpretations and applications.

Trichloroethylene (TCE), a widely used industrial solvent, is not very toxic in short-term exposure, but questions about its possible carcinogenicity following long-term exposures have been debated for over two decades. High doses of TCE produce liver tumors in mice and kidney tumors in rats. The human evidence is inconsistent – some large studies on TCE-exposed workers fail to corroborate the apparent elevations of kidney cancer or non-Hodgkins lymphoma seen in a few smaller studies with problematic design. Despite new studies and increasingly complex analysis, many toxicologic questions remain.

Most environmental issues concern local contamination of groundwater. TCE groundwater plumes associated with old waste-disposal sites and former industrial facilities constitute the country's most common site-specific environmental contamination issue. Total TCE remediation costs nationwide run into several billions of dollars. At many sites, the factor that drives cleanup requirements is vapor intrusion – volatilization of TCE from groundwater plumes into indoor air *via* cracks in building foundations.

EPA's Different Bases for Estimating TCE Cancer Risk



Based on U.S. EPA (2001). Trichloroethylene Health Risk Assessment: Synthesis and Characterization. Office of Research and Development, Washington, D.C. EPA/600/P-01/002A. August.

The U.S. EPA (and its external expert review panel, the Science Advisory Board, or SAB) (U.S. EPA, 2002 and U.S. EPA, 2001) have struggled with how to characterize the potential for human cancer risks. The EPA withdrew its former assessment from its publicly available IRIS database in 1989, pending the resolution of issues raised in SAB review, neither supporting its old assessment, nor providing a new one. (In practice, however, the withdrawn assessment continues to be generally applied.)

> *…the draft document identifies no single quantitative basis for estimating TCE cancer potency.*

After several years of renewed efforts, the EPA released a draft reassessment of TCE health effects in 2001. This draft describes TCE as a likely human carcinogen. Importantly, unlike past agency practice, the draft document identifies no single quantitative basis for estimating TCE cancer potency. Instead, a 20-fold range of values is provided, comprising a number of alternative slope factors, each based on a different animal or human dataset and a different analytical approach. Although many of the underlying studies examined TCE inhalation, the slope factors are all expressed in terms of extra risk per mg/kg-day, the approach used for oral exposures. No explicit means to assess inhalation exposures is provided.

Because the primary exposure of concern in many site-specific assessments is inhalation of indoor air, the lack of an inhalation-specific unit risk has proved problematic. Several EPA regional offices, as well as various state agencies, have proposed oral-to-inhalation extrapolation approaches, but not all the chosen methods are consistent, and some contradict the methods applied within the EPA document (which is itself internally inconsistent).

When the largest oral slope-factor is combined with the EPA default method for oral-to-inhalation extrapolation, one arrives at an "implied" inhalation unit risk that is 67-fold higher than the old withdrawn IRIS value. Without guidance as to how to do otherwise, this is the approach being adopted by some states and regional offices, even though its application

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Assessing Vapor Intrusion – Modeled *vs.* Measured Data

When assessing indoor air risks, both modeling and monitoring approaches have their benefits and limitations.

Assessing potential vapor transport from subsurface contamination into indoor air is an important part of many risk assessments performed today. The U.S. EPA has developed a building infiltration model based on the Johnson and Ettinger model (U.S. EPA, 2003) for contaminant partitioning and subsurface vapor transport into buildings. Depending on the viewpoint, the EPA's model is either too conservative or not conservative enough. Alternatively, actual indoor air measurements can be taken, but the associated uncertainty restricts their usefulness as well.

> *If possible, a combination of direct air measurements and vapor intrusion modeling is the best approach.*

The EPA's building infiltration model has certain benefits. It is a widely-available model that can be readily applied to most sites. It can estimate incremental risks associated with actual soil, groundwater, or soil-gas data, or it can calculate risk-based concentrations (*i.e.*, screening levels) corresponding to a specified target risk level. The model can incorporate various site-specific hydrogeological and structural properties of the site/building, or it can employ all model defaults. The accessibility and flexibility of this model facilitates its widespread use.

On the other hand, all models have their limitations, and the EPA's building infiltration is no exception. It is highly sensitive to certain input parameters such as water-filled soil porosity and soil vapor permeability, which are parameters not often collected as part of site investigations. As with all models, the model's results are only as good as its weakest link, *i.e.*, poor data lead to poor results. Relying solely on model default values, however, generally results in an over-prediction of indoor air concentrations and risks. As such, using the model default values can produce the counterintuitive result of unacceptable indoor air risks even when assuming the presence of a contaminant in groundwater at its Maximum Contaminant Level. In addition, the model uses many simplifying assumptions, and therefore is not applicable for all sites, *e.g.*, those with subsurface preferential pathways could have significantly increased vapor transport that is not accounted for by the model.

Alternatively, one could collect actual indoor air measurements, rather than having to resort to using a model. Unfortunately, interpreting such results is not straight-forward, because many variables can influence indoor air measurements. Foremost, it is complicated to determine the source of any contaminant being measured indoors, *i.e.*, whether it is coming from the subsurface below the actual structure or from another outdoor or indoor source such as from some lifestyle-related activities. Another option is taking direct soil-gas measurements which isolates the subsurface contribution and has other advantages, such as integrating the soil and groundwater contribution to the vapor contamination and eliminating the uncertainty in chemical partitioning. However, it is difficult to ensure that the soil-gas samples collected will be representative of conditions beside or beneath the actual structure. Another confounding aspect of indoor air monitoring is that current air analytical techniques have a limited ability to detect volatile organic compounds (VOCs) at their risk-based criteria.

If possible, a combination of direct air measurements and vapor intrusion modeling is the best approach. The key to obtaining accurate model predictions is to be aware of the model's sensitivities and limitations, and to collect site-specific data focusing on the sensitive model input parameters. Measured soil-gas and/or indoor air data can be used to reality check the model predictions and to help identify whether additional site-specific information should be collected to improve the model.

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References:

U.S. EPA. 2003. Johnson and Ettinger (1991) Model for Subsurface Vapor Intrusion into Buildings. Accessed on-line November 2003 at http://www.epa.gov/superfund/programs/risk/airmodel/johnson_ettinger.htm.

BY THE WAY...

Use and production of TCE is on the rise in part due to its use as a replacement for stratospheric ozone-depleting chemicals such as TCA which can no longer be produced in the U.S. under the 1990 Clean Air Act Amendments.

Source: *Chemical Market Reporter*, Volume 262, Number 3: 31, July 22, 2002 and U.S. EPA 1997.

What's New at Gradient

Leslie A. Beyer and **Dr. Thomas A. Lewandowski** recently became Diplomates of the American Board of Toxicology (DABT) after passing the 2003 certification exam.

Teresa S. Bowers has recently been appointed by the U.S. Secretary of Health and Human Services to a four-year term on the National Advisory Environmental Health Sciences Council of the National Institutes of Health.

Gradient's Seattle office is moving into town. The new address, effective mid-January, will be: Plaza 600 Building, Suite 803, 600 Stewart Street, Seattle, Washington 98101-1230. All electronic addresses will remain the same. New phone numbers will be communicated shortly.

Upcoming Presentations

Pasadena, CA. January 26-27, 2004. Mealey's Water Contamination Conference: (http://www.mealeys.com/conferences/sem_Wat0104.html)

- **Eric Butler**. "Exposure and the Age Dating of Chemical Plumes."
- **Peter Valberg**. "Explaining Risk to Judges, Juries and Communities."

Baltimore, MD. March 21-25, 2004. Society of Toxicology Annual Conference Poster Presentations:

- **Barbara D. Beck**. "The Role of Methylation in Arsenic Toxicity and Risk: The Enigma Continues."
- **Leslie A. Beyer, Mara R. Seeley,** and **Barbara D. Beck**. "Evaluation of Exposure to Metals on Reusable Shop Towels."
- **Thomas A. Lewandowski** and **Barbara D. Beck**. "Potential Health Effects of Exposure to Methylenedianiline and Toluenediamine During Polyurethane Foam Manufacturing."
- **Ari Schoen** and **Barbara D. Beck**. "Evidence from Epidemiological and Mode of Action Studies Support a Non-linear Dose-Response Relationship for Arsenic-Induced Carcinogenesis."
- Bryan K. Shipp, **Eric M. Dubé**, **Barbara D. Beck, Mara R. Seeley, Kathleen A. Radloff, Sunessa Schettler, and Cathy Petito Boyce**. "Development of a Risk Assessment to Evaluate Human Health Risks from Exposure to Tebuconazole Used as a Wood Preservative."

Recent Articles

Lewandowski, T.A., R.A. Ponce, J.S. Charleston, S. Hong, E.M. Faustman. 2003. Effect of methylmercury on midbrain cell proliferation during organogenesis: Potential cross-species differences and implications for risk assessment. *Toxicol. Sci*. 75(1):124-133.

Petito Boyce, C. and M.R. Garry. 2003. Developing risk-based target concentrations for carcinogenic polycyclic aromatic hydrocarbon compounds assuming human consumption of aquatic biota. *J. Toxicol. Environ. Health* 6(Part B):497-520.

Turmoil about TCE: The EPA's Controversial Reassessment of Cancer Risks

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leads to risk concerns for even typical and ubiquitous background indoor air levels of TCE.

The EPA draft reassessment itself, however, calls on users to choose a slope factor from the range provided, based on judgments about which alternative is most appropriate to the particular exposed population and route of exposure, but no selection guidance is provided. Scientifically sound arguments for making appropriate choices for inhalation exposure are available, however, and they typically lead to much less draconian risk projections.

The EPA's TCE reassessment has been controversial and has been critiqued by the SAB and by outside parties. Reportedly, the EPA's own Science Advisor has urged agency risk assessors to back away from applying it until some of the issues can be resolved. The EPA will submit a revised document to the National Academy of Sciences for a special expert-panel review, a process not expected to be completed until 2006.

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U.S. EPA, Science Advisory Board. 2002. Review of Draft Trichloroethylene Health Risk Assessment: Synthesis and Characterization: An EPA Science Advisory Board Report. EPA-SAB-EHC-03-002, December 2002:1.

U.S. EPA. 2001. Trichloroethylene Health Risk Assessment: Synthesis and Characterization. EPA/600/P-01/002A. August 2001:4-29.

Guest Editorial: Real Progress in Bioremediation of Chlorinated Solvent Plumes

Recent advances in chlorinated solvent plume remediation are debunking some established scientific dogma.

> *… it has since become common knowledge that most chlorinated solvents, including PCE and TCE, are readily biodegradable under anaerobic conditions.*

The technical challenges to remediating chlorinated solvent plumes stem from the physical properties of the solvents themselves. Trichloroethylene (TCE) and perchloroethylene (PCE) releases to an aquifer typically occur as spills of fresh product or spent solvent wastes. These materials are liquids at ambient conditions, are sparingly soluble, have low viscosities, and are denser than water. As a result, these dense non-aqueous phase liquids (DNAPLs) readily migrate downward in aquifer systems, and form persistent sources for dissolved-phase contaminant plumes. These DNAPL source areas are very difficult to locate, delineate, and treat or remove. Traditional pump-and-treat approaches to remediating chlorinated solvent plumes have little effect on source areas, and have therefore been largely ineffective.

In addition to their challenging physical properties, PCE and TCE were once thought to be both chemically and biologically recalcitrant in the environment. As recently as the 1980s, these compounds were believed to be non-biodegradable and toxic to aquifer bacteria. During the early to mid 1990s, this paradigm was overturned, and it has since become common knowledge that most chlorinated solvents, including PCE and TCE, are readily biodegradable under anaerobic conditions.

Related discoveries have enabled the development of engineered bioremediation approaches for aquifers where natural biodegradation processes are not sufficient to meet remedial objectives for the site. The two principal approaches to engineered bioremediation are biostimulation and bioaugmentation. In situations where adequate dechlorinating bacteria are present, biostimulation, which involves the addition of organic carbon substrate to the aquifer to serve as food for the dechlorinating bacteria, can be a viable approach. If adequate dechlorinating organisms are not present, bioaugmentation is used to seed the aquifer with a culture of dechlorinating bacteria. Bioaugmentation has been successfully used at a number of sites in the U.S., including Air Force bases and Superfund sites.

During the late 1990s, another significant paradigm was overturned: the belief that there is a "toxic threshold," or concentration of PCE or TCE, above which even dechlorinating bacteria could not survive. Pioneering work at Cornell and Stanford Universities showed that certain bacteria could thrive and fully biotransform PCE and TCE at concentrations of hundreds of ppm, right up to aqueous saturation. This discovery opened the doors to the new and rapidly developing field of biological treatment of chlorinated solvent DNAPL source areas – an approach which may finally provide a cost-effective solution to dealing with chlorinated solvent DNAPL sources.

Thus, as our understanding of the magnitude of chlorinated solvent contamination in the environment grows, so too does our understanding of viable technologies to address it.

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Bioremediation of Chlorinated Solvents Consortium
Remediation Technologies Development Forum

In the next issue:

Understanding Acute Risks

Assessing Acute Risks

Health Risks and U.S. Forces

Guest Editorial: Information Sensitivity and Management

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Risk Science & Application

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Printed on recycled paper with soy inks