A View of the Evaluation of the Vapor Intrusion Pathway from Within the Petroleum Industry

by Victor Kremesec, Harley Hopkins, and Roy Thun

In this perspective paper, we present our view of the petroleum industry's efforts on evaluating the vapor intrusion (VI) pathway, examine issues with the U.S. Environmental Protection Agency's (EPA) *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway,*[1] highlight current research efforts, and propose a screening approach that would be useful until more data and/or refined analytical techniques become available.

For the petroleum industry, as well as many environmental consultants and state regulators, the need for realistic screening criteria for VI is paramount. Without adequate methods to reach definitive conclusions on chronic exposure to vapors, unrealistic or overly conservative screening criteria may lead to unnecessary site evaluations, stakeholder anxiety, and wasted resources.

There are three important parts to evaluating the VI pathway: identifying emergency or acute situations; screening criteria for determining sites that need to be evaluated for chronic exposure; and evaluating long-term or chronic exposure. In the majority of emergency/acute situations, we believe that the petroleum industry has taken appropriate and immediate action. Indeed, there is extensive industry experience in identifying such situations and both federal and state jurisdictions have well-established guidance in this area. However, in the case of screening and evaluating for chronic or long-term exposures, there is still considerable effort needed to identify the characteristics and conditions that pose significant risk.

An ideal screening guidance for chronic exposure to vapors would clearly distinguish the sites that are most at risk and require immediate action from the sites with enough uncertainty that additional scrutiny is warranted. At issue is the ability to accurately separate the potential effects of VI from a specific subsurface source versus background concentrations. In many cases, background or ambient conditions present a greater than 10^{-5} risk (e.g., in the case of benzene), while, in general, assessments over the past decade have shown that petroleum hydrocarbon-impacted soil or groundwater do not typically result in indoor air concentrations that exceed this risk level. Factors that influence VI analysis include indoor sources and activities, building construction and ventilation, retardation caused by a slab or floor, biodegradation, and the physical transfer of chemicals from soil or groundwater to soil gas. Consequently, due to the variety of known factors, it is difficult to establish useful and accurate screening criteria.

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At the same time, there are considerable unresolved issues concerning site-specific evaluations of the potential for chronic exposure in EPA's *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway* (published November 2002).[1] In fact, the guidance is conflicted on this subject. For example, models are recommended for use in the development of VI screening criteria, but they are not recommended for use during site-specific evaluations. The American Petroleum Institute (API) and others have submitted to EPA written and verbal comments concerning the recommended process for site-specific evaluations, and this continues to be an area of rich scientific debate.

HISTORICAL PERSPECTIVE

The petroleum industry has been evaluating issues surrounding the VI pathway, with varying degrees of rigor, for approximately 15 years. This work has focused more on the fate and transport of petroleum hydrocarbons in the vadose zone, rather than the development of general VI screening criteria.

Results from early fieldwork highlighted the

Victor J. Kremesec, Jr., is advisor, remediation management and Roy I. Thun is environmental business manager, both with Atlantic Richfield Company, a BP-affiliated company, Warrenville, IL. Harley H. Hopkins is senior environmental scientist with the American Petroleum Institute, Washington, DC. *The authors thank Robert Ettinger and Tom McHugh for their review and comments of this article.*

inability to conclusively evaluate the VI pathway. Indoor air sampling was common in situations when there was a perceived threat and measured concentrations were compared to outdoor or ambient concentrations for evaluating risk. Elevated concentrations of compounds of interest were often due either to indoor sources or preferential pathways, such as dried-up traps in plumbing or wet basements. Since most compound concentrations could not be distinguished from background concentrations, investigators recognized a need to quantify fate and transport

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of petroleum hydrocarbons in the vadose zone. Their studies identified biodegradation and the reduced vapor diffusion in tight wet soils as factors that reduced the flux of hydrocarbons upward toward buildings.

The petroleum industry took the first major steps in evaluating this pathway for volatile organic compounds (VOCs). In 1991, researchers for Shell Oil Company, Paul Johnson and Robert Ettinger, published their Johnson and Ettinger, or "J&E," Model for screening vapor attenuation between a subsurface vapor source and a building's interior.[2] Although there is some debate within the petroleum industry on the ability of the J&E Model to accurately predict indoor air concentrations, API and others continue to study, evaluate, and improve on this model. Recent studies include the addition of biodegradation and soil layering,[3,4] a guide to help users focus on the most critical parameters,[5] and a study comparing attenuation factors derived from a Colorado Department of Transportation (CDOT) site to predictions made using the J&E Model.[6]

The petroleum industry has also funded several studies to improve the understanding of critical processes and reduce uncertainty when screening the VI pathway. These include flux limitations from groundwater,[7] the impact of background concentrations,[8] and the development of three-dimensional models for VI screening and analysis.[9] Most recently, API completed a user manual for developing sampling plans and the methods for sampling and analysis of soil gas, as part of an evaluation of the VI pathway.[10] Over the years, API and member companies have provided EPA and state agencies with the results of these and other scientific analyses and site-specific evaluations for use in better understanding and regulating the VI pathway. A prime example of this was the petroleum industry's support for the inclusion of the VI pathway and the J&E Model in the ASTM Risk Based Corrective Action (RBCA) Standard in 1995.[11]

EPA GUIDANCE

In November 2002, EPA issued its *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway.*[1] Initially developed to assess the potential for VI under the Human Health Assessment process for Resource, Conservation, and Recover Act (RCRA) Environmental Indicators, the guidance was later expanded to apply to other RCRA programs, including brownfields and Superfund, as a result of widely publicized cases of chlorinated organic compound vapors found to be intruding into homes in Colorado. EPA does not recommend that the draft guidance be used for evaluating petroleum underground storage tanks (USTs) due its "conservative" nature (more below); however, its publication has spurred many state regulatory agencies to reevaluate this pathway and issue their own guidance applicable to USTs. EPA has acknowledged that its draft guidance was based upon developing science, and has stated that it would collect and evaluate additional data before issuing a final version in 2005.[12]

To develop the attenuation factors used to calculate VI screening concentrations, the EPA guidance used default parameters and no biodegradation along with a very conservative view of available data (such as a limited attempt to consider background). Attenuation factors are defined as "ratios of concentrations between two points" (e.g., the ratio of indoor air concentration for a constituent to the concentration of that constituent immediately below the building slab, or concrete floor). Such factors are functions of the physical and biological processes that govern the transport of compounds between the two points.

EPA's default assumptions have resulted in the following attenuation factors:

- 0.1 from immediately below the building slab to indoor air (the most complex factor because it is highly dependent upon the building's construction and ventilation);
- 0.01 from a "near source" soil-gas concentration to indoor air (this assumes a sandy soil that results in a factor of 10 attenuation due to diffusion through the vadose zone and no biodegradation); and
- 0.001 from groundwater to indoor air (a factor of 10 is allowed for the diffusive resistance across the capillary fringe) and then Henry's law partitioning between the soil gas and groundwater is applied.

The default attenuation factors in the latter two bullets can be further reduced for nonsand soil types that increase the diffusive resistance through the vadose zone.

An example of the "conservativeness" of EPA's draft guidance is that it recommends further screening if benzene concentrations in groundwater are equal to or exceed 14 parts per billion (ppb; e.g., 10^{-5} excess risk case). If the screening fails, the soil type can be taken into account, which could raise the screening level by a factor of 10 (e.g., 140 ppb for silty vadose zone soils). If this level were exceeded, buildings located above the benzene plumes and 100 feet laterally beyond the plume would be subject to further screening, most likely through the collection of site-specific data. However, it is the consensus of industry professionals and many regulators, based upon experience and the results of studies described below, that EPA's recommended screening

concentrations are too low and will result in unnecessary detailed site-specific investigations conducted at many sites where experience has shown there likely would not be a problem from VI.

CURRENT EFFORTS

Recognizing the need for data, EPA has been holding workshops and seminars across the country,[13,14] inviting new data and analytical techniques to contribute to the development of its "final" guidance document.[15] Several states, including California, Indiana, and Pennsylvania, are also conducting VI investigations into the VI pathway and state regulatory agencies have formed a Vapor Intrusion Team within the Interstate Technology & Regulatory Council in an attempt to bring consistency to state guidance. The petroleum industry is participating in most of the state-led efforts. In addition, the U.S. Department of Energy and the Petroleum Environmental Research Forum conducted a workshop in January 2004 to highlight important issues and possible solutions for reducing uncertainty in evaluating the VI pathway.[16]

Many useful data sets and analyses are emerging in this area of study, and we will attempt to highlight below some of the most pertinent work that supports more realistic VI screening criteria. Some conclusions from these research efforts include

- background concentrations confound the analysis of most data sets and need to be properly accounted for if a meaningful attenuation factor across the foundation slab is to be found;
- the assumed 0.001 attenuation factor from groundwater to indoor air is likely too high;
- diffusive transport for nondegrading compounds through the vadose zone seems to be well represented through improved versions of the J&E Model; and
- biodegradation of petroleum hydrocarbons appears to be occurring to some degree and, therefore, it should be accounted for.

The strong confounding influence of background concentrations in VI screening has been recognized in numerous research presentations, and an entire session was devoted to the subject at the 2004 Midwestern States Risk Assessment Symposium in Indianapolis.[17] Recent studies to account for background concentrations have focused on using several different methods during screening:[18] the use of ratios of constituents in gas samples,[19] finding and using constituents that do not occur in ambient or indoor air, or using the measured impacts of high concentration sources that would "swamp" background concentrations.[20] Use of these methods strongly suggests that the attenuation factor from immediately below the building slab to indoor air should be significantly less than the EPA's current recommended value of 0.1.

Last year, Folkes et al.[21] presented data from Redfield, CO (a site with chlorinated hydrocarbon contamination and little biodegradation) that suggests that the attenuation factor from groundwater to indoor air should be 2–4 orders of magnitude less than the current EPA default value of 0.001. A summary of the 2004 EPA workshop in San Diego, CA, also suggests that the factor of 0.001 should be decreased by at least an order of magnitude.[12] Thus, while there are discrepancies among the data sets, the value of 0.001 is, in our opinion, overly conservative.

It is a known fact that petroleum vapor will biodegrade aerobically in the subsurface in the presence of oxygen, and there have been numerous studies showing significant reductions in hydrocarbon concentrations in the vadose zone.[4,9,22-24] These studies, which employ vertical soil-gas profiles, show hydrocarbon concentrations decreasing and/or oxygen increasing from deep to shallow levels at all sites, indicating that biodegradation is occurring to some extent in the soil. Attempts to correlate the potential or degree of biodegradation with basic site characteristics have so far had mixed results.[4] Additional modeling and fieldwork must be done to better understand oxygen transport beneath buildings. However, it is clear that biodegradation occurs to some extent and should be accounted for in the screening values for petroleum constituents.

To be sure, there are uncertainties. For example, in August 2004 Kuehster et al.[25] presented data showing that indoor air concentrations can vary by 1.5 orders of magnitude over the course of six years. Much of this variability is due to a building's ventilation and occupant lifestyles, although there are some seasonal effects. Similarly, the three-dimensional model investigation by Parker[24] concluded that predicted concentrations could easily

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vary by two orders of magnitude due to the uncertainty in parameter values and analysis of the CDOT data[6] highlighted data quality issues and also found that model predictions can vary by 1.4 orders of magnitude. These uncertainties show the difficulty associated with screening individual sites. However, the results to date indicate that conclusions can be made in a general sense to allow proposal of screening guidance based upon site-specific data.

OUR RECOMMENDATIONS

Despite the fact that significant uncertainties in the available data and analysis remain, there is a sound technical basis for proposing values of attenuation factors and a methodology for calculating screening concentrations. In its guidance, EPA has focused on using a "total" attenuation factor from groundwater to indoor air for all screening criteria. In our opinion, the attenuation factor should be broken into three "compartments": subslab or near foundation to indoor air; transport through the vadose zone; and transport through the capillary fringe (assuming that groundwater is the source). Such a methodology allows us to make the below recommendations based upon the currently available data. Section VB of EPA's draft guidance (Secondary Screening—Question 5: Semi-Site Specific Screening) is already a start in this direction. We believe it would allow for better flexibility in developing more accurate VI screening values for different site conditions and characteristics.

1. For the subslab-to-indoor air attenuation factor, we recommend adopting the results of McHugh et al.[8] This careful analysis of chlorinated data from the Endicott, NY, site[20] using high source concentration data has determined that the attenuation factor should be set at 0.003 rather than the default factor of 0.1 currently used. This factor of 33 reduction in the default value would seem to be well with the bounds of the analysis of the chlorinated data at the Redfield, CO, site.[21] It is also near the value calculated with the EPA default building parameters.[26]
2. We believe that the data support an attenuation factor of at least 0.1 for biodegradation of petroleum constituents in the vadose zone.[4,22,23] This biodegradation factor could be eliminated when the depth to water from the foundation is less than 3 feet, or raised when there is likely oxygen transport beneath the structure or hydrocarbon concentrations were low. The conditions for increasing the factor can probably be better defined by the three-dimensional modeling by Johnson and students[9] and Parker.

> It is a known fact that petroleum vapor will biodegrade aerobically in the subsurface in the presence of oxygen.

3. We support the use of the J&E Model, including highly saturated, low permeability strata to describe the transport of nondegrading compounds through the vadose zone.[3,4] This would likely result in adjustments to the attenuation factor similar to those recommended in Section 5 of EPA's draft guidance. We also recommend continuing to use the approximate factor of 10 reduction in the attenuation factor between groundwater and soil gas due to diffusive resistance in the capillary fringe and soil vapor/groundwater partitioning.[1]
4. Finally, we recommend that typical ambient air concentrations be used as the basis for developing VI screening values. The ambient air values are typically slightly above 10 excess risk and the draft guidance recommends the use of a 10^5 risk level. This may not satisfy some in the regulatory community, who insist that criteria be based upon a 10^{-6} excess cancer risk. At such a low-risk level, it is virtually impossible to effectively determine the impacts via the VI pathway because of the low screening concentrations that would result.

In addition, questions concerning the recommendations or restrictions for applying the screening criteria in EPA's draft

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guidance have been raised. They include

1. The recommendation to perform the investigation in a 100-feet radius around a groundwater plume apparently has no data to support it,[18] particularly when the groundwater plume boundaries are well defined—*we recommend dropping this requirement.*
2. McHugh et al.[7] suggested that, in many cases, the amount of contaminant required to sustain chronic exposure cannot be maintained by the transport of contaminated groundwater beneath a structure; in other words, there may not be enough mass available to perpetuate a long-term exposure—*we believe that this analysis may be useful in site-specific evaluations.*
3. EPA's draft guidance recommends that the screening process not be applied to sites with less than 5 feet of separation between groundwater and a building's foundation, yet the J&E Model should be applied. Paul Johnson[14] has stated that there is no scientific justification for this restriction—*we recommend dropping this restriction.*
4. EPA's draft guidance precludes the application of screening criteria if the depth to water from the building's foundation is less than 15 feet when preferential pathways are present—*in our opinion, preferential pathways should be dealt with separately and not in conjunction with the depth-to-water ratio.*

CONCLUSION

We believe that the above recommendations are well supported by sound scientific research. We also believe that they would provide more reasonable generic evaluation criteria and flexibility in developing site-specific screening levels that experienced investigators, working both in industry and regulatory agencies, would feel are protective, while identifying situations in need of further evaluation. It is our belief that adoption of these recommendations would provide value to all stakeholders in VI cases because they would alleviate much of the anxiety within the public, private, and regulatory sectors created from overly conservative guidance and regulation, and significantly reduce the unnecessary waste of resources. Further, we believe that investigation of the remaining sites that exceed the screening criteria will lead to a determination of whether additional changes to the VI guidance are needed or justified. **em**