

## Remediation

# Reevaluating the Upward Vapor Migration Risk Pathway

by Blayne Hartman

When we last addressed this topic in November 1997 (LUSTLine #27, "The Upward Migration of Vapors"), the article began with a prologue indicating that the human health risk due to the upward migration of subsurface contaminants in the vapor phase is a growing concern to regulatory agencies. Four years later, it is safe to say that concern among regulatory agencies surrounding this risk pathway has grown quite considerably. It now seems that federal, state, and local agencies across the country know about calculating risk using the Johnson-Ettinger model. In fact, U.S. EPA has a 63-page User's Guide for the Johnson & Ettinger (J-E) model and another Supplemental Guidance document currently posted on its web site ([www.epa.gov/correctiveaction/eis/vapor.htm](http://www.epa.gov/correctiveaction/eis/vapor.htm)). Custom versions of the J-E model are commonplace from state to state and in some states, from county to county.

But the proper approach for assessing this risk pathway is still under debate. In May 2001, by direct request from the governor, the Michigan Environmental Science Board evaluated the use of the J-E model and issued a report that concluded that the model was appropriate, although the committee expressed confusion over the model's failure to adequately predict trichloroethylene (TCE) concentrations from a Colorado study. Earlier this year, the Denver Post brought even more attention to the debate over this risk pathway and the Johnson-Ettinger model in a series of articles calling the model "flawed," attacking U.S. EPA's use of the model, and even accusing EPA of a cover-up about a "botched toxic-gas probe" ([www.denverpost.com/Stories/](http://www.denverpost.com/Stories/)).

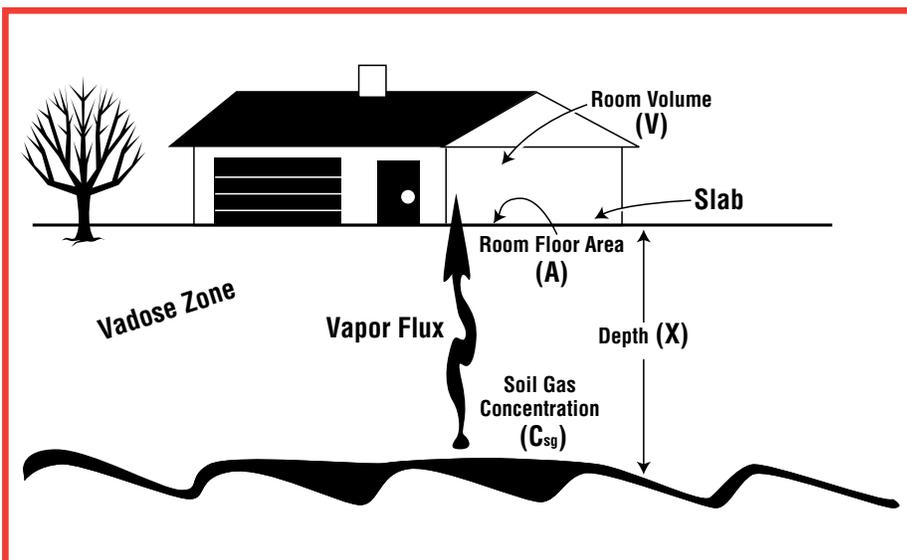
Confused? You're clearly not alone. So, what better reason to take another look at the upward vapor risk issue and see if we can clear up some of the confusion that currently exists.

## A Review of the Concepts

Simplified, the Johnson-Ettinger model allows us to compute the indoor room concentration from the upward flux of a contaminant in the vapor phase. The vapor flux into a building is computed from Fick's first law, requiring measurements of the soil vapor concentration at some depth underlying the structure. Soil vapor concentrations may be measured directly. Alternatively, in the absence of actual soil vapor data, soil vapor concentrations are commonly calculated from soil and groundwater data, assuming equilibrium conditions, using equations based on Henry's Law constants and soil-to-water partitioning constants (ASTM, 1995). *And here lies the source of most of the problems that are currently being experienced with the use of this model.*

## Remember the Salad Dressing

Immediately following the deluge of equations in my 1997 article, I gave a warning about using these equations to calculate soil vapor data. Let's repeat some of the text here to refresh our memories:



You must recognize that the equations used to calculate the soil vapor concentration from soil-phase data, water-phase data, or free product assume equilibrium partitioning between the phases. Equilibrium partitioning is obtained only if a system is well mixed. This condition is very rarely accomplished in the subsurface, because there are no blenders or stirrers present to homogenize the vapor, soil, and groundwater.

A common analogy used to illustrate this mixing concept is the preparation of a salad dressing using oil and vinegar. When the ingredients are initially added to the container, they fall into separate layers; the container must be shaken to mix the ingredients. If the container is not shaken, the oil and vinegar mix very slowly, "equilibrium is not reached," and the resulting salad dressing does not taste very good.

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Indeed, the results of published studies comparing measured soil vapor concentrations to soil vapor values calculated from groundwater using Henry's constants indicate that calculated values are often overestimated by factors of 10 to 100. Contaminant partitioning from soil to soil vapor is also likely to be far from equilibrium.

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My personal experience, based on measurement of contaminated soil and soil vapor at the same location, is that in the case of hydrocarbons, calculated soil vapor values from soil-phase data often *overestimate* actual soil vapor concentrations by factors of 10 to 1,000. In the case of chlorinated hydrocarbons, calculated soil vapor values from soil-phase data often *underestimate* actual soil vapor concentrations, perhaps due to the presence of contaminant vapor clouds infiltrating into the vadose zone from the surface and creating higher soil vapor concentrations. (See LUSTLine #28, "The Downward Migration of Vapors.")

### The Key Conclusion

If calculated soil vapor values can differ from actual values by factors of 10 to 1,000, then the calculated vapor fluxes, and in turn, the calculated room concentrations using any version of the J-E model will be off by a similar factor. In other words, the error introduced by the calculated soil vapor data is likely to be far greater than errors introduced by any of the other parameters used in the model (e.g., porosity, advection, multi-layers).

### What Happened in Denver?

The EPA was under fire because indoor air measurements showed the presence of a contaminant (1,1 DCE) in homes at concentrations exceeding 1 in 1 million risk levels, yet indoor air values calculated from the J-E model indicated values below this risk level. The conclusion reached by the press was that EPA was using a faulty model.

But upon inspection, one learns that soil vapor values were not measured but calculated from groundwater values. Further adding to the potential error, the groundwater values themselves were not measured under the majority of the homes, but were estimated from contours of surrounding monitoring well data.

These are two very big potential errors that, combined, could introduce errors of two to three orders of magnitude in the soil vapor value used in the model calculation. While the situation here is a little more complex, the unfortunate fact is that EPA is getting torched in the press over the use of a bad model when, in fact, the real reason might be the inaccuracy of the data input into the model (i.e., the soil vapor concentration).

The "moral" of this story is that one must be careful about calculating soil vapor concentrations from groundwater- or soil-phase data. Many people feel that soil vapor values calculated from groundwater or soil data are more dependable than measured values because they show less variability than measured soil vapor data. While it is true that actual soil vapor data will show more variability than groundwater values, the gain in precision does not come close to offsetting the loss in accuracy. If soil vapor data are collected properly, the variability in the measurements (i.e., precision) from day to day is generally less than a factor of two. This is much smaller than errors of a factor of 10 to 1,000.

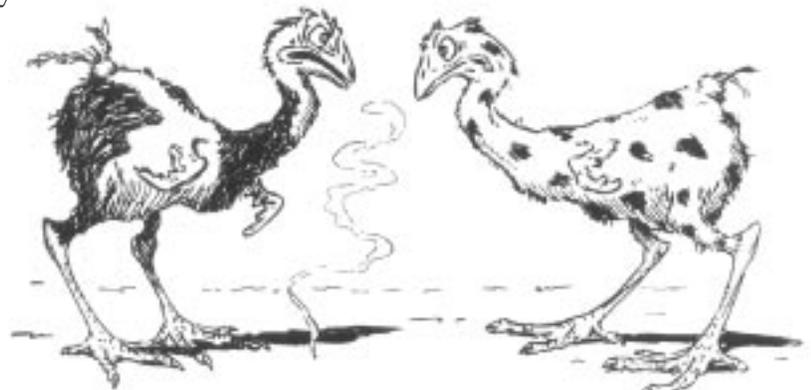
### The Optimum Approach for Evaluating the Upward Vapor Migration Risk Pathway

Okay, so what's the optimum technique for determining the upward vapor migration risk? In my experience, the J-E model, limitations aside, tends to *overestimate* risk in nearly all cases if the proper soil vapor values are used, and hence is a conservative approach to the problem. However, the likely fallout of the negative press on the Denver site is that there will be a tendency to move away from the use of the J-E model and toward evaluating this risk pathway using surface flux-chamber measurements and indoor air measurements.

Beware, because these techniques have their limitations also, principally the following:

- A lack of data points (1 or 2 measurements over limited time intervals)
- Potential for contamination from sources besides flux from the bottom (with an indoor air measurement, how do you know where the contaminant came from?)
- No knowledge of what lurks below
- High potential for blanks that are then misinterpreted as fluxes
- An unsophisticated end-user (i.e., consultants who can't interpret the results)

The point is not that these techniques are not valid to use, but that they too have limitations that need to be considered before selecting the best method to use. You wouldn't consider proposing or accepting a site-assessment report with only one analysis from one or two borings, would you? So why would you accept only one or two flux-chamber or indoor-air measurements to close this risk pathway?



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Until we get a better database from which to make a reasonable conclusion as to the optimum approach, I strongly recommend the following:

- Use J-E type models with actual soil gas data. Analyze the soil vapor at a reasonable number of points (minimum of four) covering the footprint of the existing or future building. Analyze soil vapor at shallower depths if samples collected at 5-feet below ground surface (bgs) indicate a potential problem. If samples are to be collected at very shallow depths (<3 feet bgs), consider installing vapor implants and measuring the soil vapor multiple times to evaluate the precision of the measurements. Refer to the article in *LUSTLine* #27 for a sampling protocol.
- For flux-chamber or indoor-air programs, take more than one measurement, collect for at least 8 hours (24 hours preferred), and collect at least one soil vapor sample under the footprint to see if anything lies below, especially at chlorinated solvent sites. ■

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