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Mr. Andrew Friedmann, Ph.D. – sent via email
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Subject: Consideration of Vapor Intrusion Pathway Modeling in the MassDEP Draft Vapor Intrusion Guidance

Dear Andy:

We wanted to write to follow up on some of the ongoing discussions in the Department's Indoor Air Guidance Workgroup regarding the use of the Johnson & Ettinger model to calculate vapor intrusion-related concentrations in indoor air at Massachusetts Contingency Plan (MCP) sites. Specifically, we have prepared this letter to follow up on Robert Ettinger's presentation at the "Data Day" meeting on 4 May 2009, but we also wanted to take this opportunity to discuss:

- Our concerns regarding the draft Guidance language's heavy reliance on measured indoor air concentrations to calculate vapor intrusion-related exposures, and
- How modeling, when properly conducted, can be a constructive tool in reducing uncertainty and building confidence in vapor intrusion pathway evaluations.

We believe that a multiple lines of evidence (MLE) approach to evaluate the vapor intrusion pathway is a useful methodology to make appropriate risk-based decisions. A decision on what data should be collected to evaluate whether vapor intrusion is occurring at an individual building and to develop exposure point concentrations (e.g., indoor air concentration measurements or soil gas/groundwater data combined with modeling) should be made based on the site conceptual model. A single data collection strategy such as requiring indoor air measurements for decision making will not be appropriate for all sites. Indoor air concentration data faces two significant challenges: temporal variability and "background" sources. Therefore, indoor air measurements are typically not used by themselves to assess the vapor intrusion pathway and other lines of evidence, including modeling, are used to reduce the uncertainty associated with indoor air measurements.

In order for modeling to be used to evaluate the vapor intrusion pathway, it must be conducted in a technically-defensible manner. Inappropriate conclusions can arise if the modeling is performed using improper inputs or assumptions. It is important to note, however, that several studies have been published demonstrating that, when conducted properly, vapor intrusion modeling can be an effective tool to evaluate the potential for subsurface vapor to migrate to indoor air.

Data Day Presentation

One key point that we made during the “Data Day” presentation is that care must be exercised when comparing vapor intrusion model results to empirical sub-surface and indoor air data. This does not mean that modeling cannot be used to evaluate the pathway. In fact, there have been several studies that demonstrate a good correlation between modeled and empirical results. When measured and modeled attenuation factors do not agree, one of the following conditions is likely the cause of this discrepancy:

- Indoor air concentration measurements are not representative of site conditions;
- Groundwater and/or soil gas measurements are not representative of site conditions;
- The conceptual model used to develop the vapor intrusion model is not suitable for site conditions; or
- Parameter values used for model inputs are not appropriate for site conditions.

During the presentation, we discussed several examples where these deficiencies were identified and where, in the absence of sufficient data evaluation, one could incorrectly conclude that modeling was not useful in risk-based decision making.

The detailed modeling evaluation conducted for the Colorado Department of Transportation Materials Testing Laboratory (CDOT-MTL) site that was discussed during our presentation is a summary of a published study (Johnson et al., 2002) and highlights several of the points listed above. A great deal of data had been collected at this site; however, through careful evaluation of the groundwater, soil gas, and indoor air data it was determined that much of these data were not representative of site conditions and should not be included in the evaluation. This is not a matter of selecting data that give a desired answer. Rather, this case study illustrates the importance of reviewing data to evaluate whether they are consistent with the site conceptual model for subsurface vapor intrusion before using those data to make decisions or to draw conclusions. If the data are not consistent with the site conceptual model for subsurface vapor intrusion, then either the conceptual model must be revised or the quality of the data is suspect.

In this study, we had sufficient data to give confidence to the site conceptual model and, therefore, excluded data that were suspect. The modeling component of this study was conducted using input parameters based on the detailed site characterization and included an analysis to assess the uncertainty of the modeled results. The study found that the modeled vapor intrusion attenuation factors compared well with the empirical values. This demonstrates that modeling may be used effectively to evaluate the vapor intrusion pathway.

The presentation also included a discussion of cases where empirical attenuation factors were positively biased by background sources and how reliance on empirical attenuation factors may lead to an incorrect conclusion regarding the significance of vapor intrusion or the reliability of mathematical modeling. The first case presented example results from the USEPA Raymark study (USEPA, 2006) as shown in Figure 1.

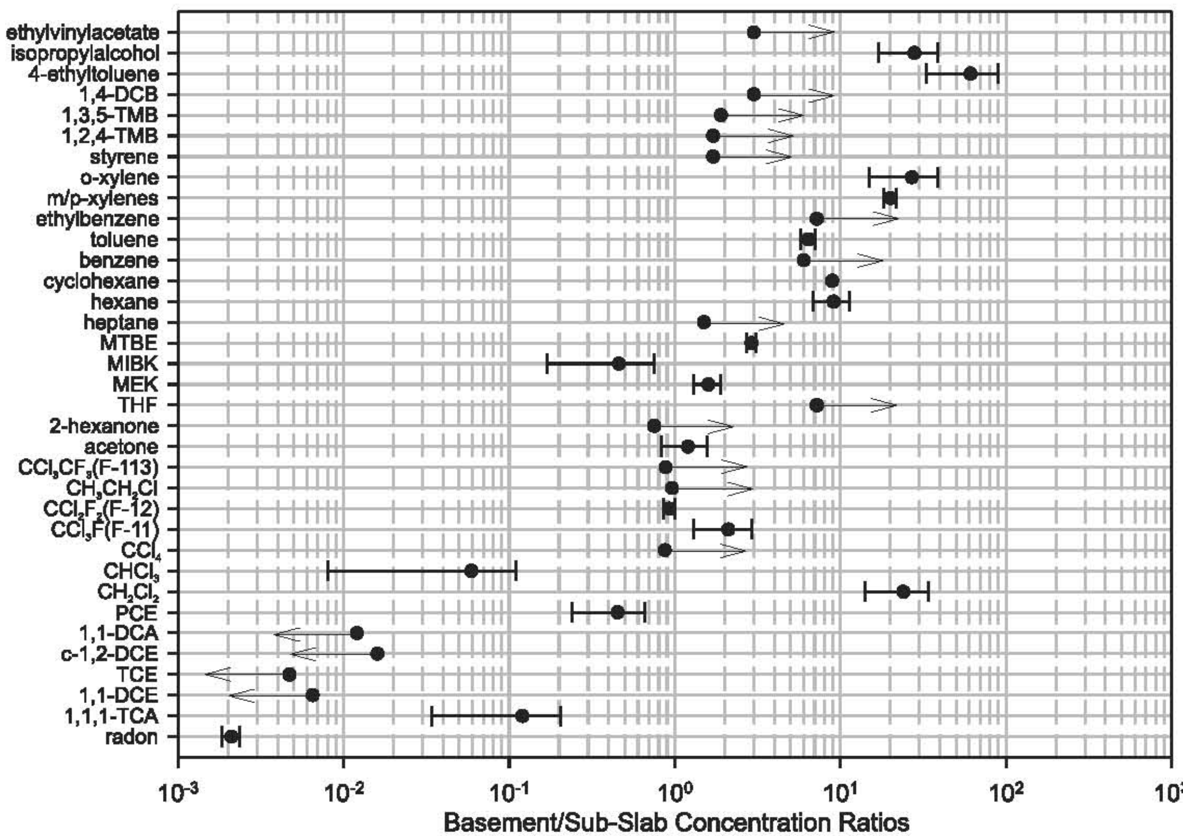
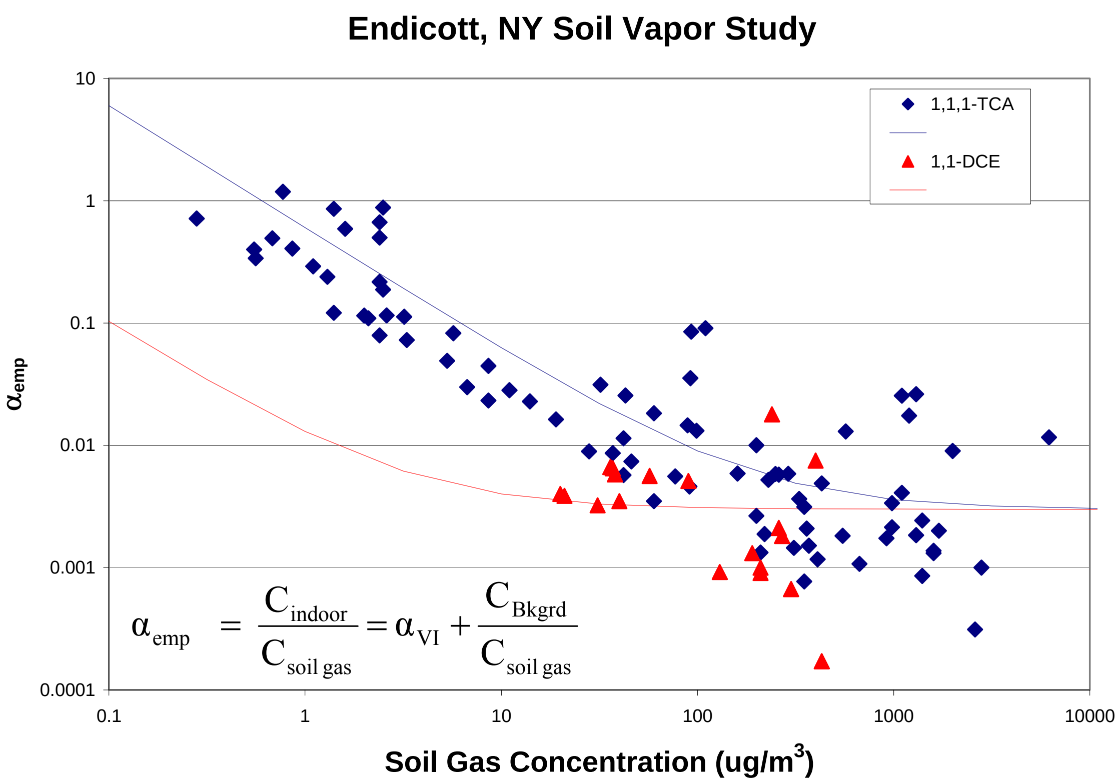


Figure 1: Empirical Attenuation Factors for a specific building (EPA, 2006)

This figure shows empirical attenuation factors for a single building (attenuation factor is equal to the ratio of the concentration of a VOC in basement indoor air to the concentration of the same VOC in a sub-slab soil gas). If the indoor concentrations were all due to subsurface vapor intrusion, then the attenuation factors would be the same for all the constituents detected. The variability in these empirical attenuation factors is predominantly a result of background sources. As shown in Figure 1, empirical attenuation factors for many of the constituents were greater than one, meaning the detected concentration in indoor air was greater than the detected concentration in sub-slab soil gas. If an empirical attenuation factor is greater than one, the concentration detected in indoor air cannot be the result of vapor intrusion alone and typically reflects the presence of indoor air sources.

In this plot, radon may be the only constituent without significant background interference that can be used to estimate the vapor intrusion attenuation factor for this building; the empirical attenuation factors for all other constituents on Figure 1 were either biased high due to background sources, or the constituent was not detected in indoor air. Note that for this home, only four constituents other than radon were detected in indoor air and had an empirical attenuation factor less than one: 1,1,1-TCA, PCE, $CHCl_3$, and MIBK. The average empirical attenuation factor for these four constituents is much larger than the empirical attenuation factor for radon (greater than 0.1 versus 0.002). Radon is not affected by background sources, so the fact that the empirical attenuation factors for these other constituents are greater that of radon indicates that the measured indoor air concentrations for 1,1,1-TCA, PCE, $CHCl_3$, and MIBK were influenced by background indoor air sources. It is likely that the significance of subsurface vapor intrusion would be over-stated if the radon data were not available for this building and an assessment of the vapor intrusion was based only on the VOC concentration measurements in indoor air.

A second case presented at the meeting illustrated the positive bias on empirical attenuation factors due to background sources through evaluation of data collected at the Endicott, NY site. These results are shown in Figure 2.



$$\alpha_{emp} = \frac{C_{indoor}}{C_{soil\ gas}} = \alpha_{VI} + \frac{C_{Bkgrd}}{C_{soil\ gas}}$$

Figure 2. Effect of background on empirical attenuation factor.

This figure plots the empirical attenuation factor as a function of soil gas concentration. As the soil gas concentration increases, the potential effect of background becomes insignificant. However, at low soil gas concentrations, the background sources can result in an over-estimation of the attenuation factor. In these low source concentration cases (i.e., cases with lower soil gas concentrations), the empirical attenuation factor would be higher than that predicted using a vapor intrusion model. The modeled results provide a more representative estimate of the subsurface vapor intrusion potential.

During the presentation, we also presented examples where mitigation systems were installed based on indoor air results. An example from the Colorado Redfields Site is shown in Figure 3.

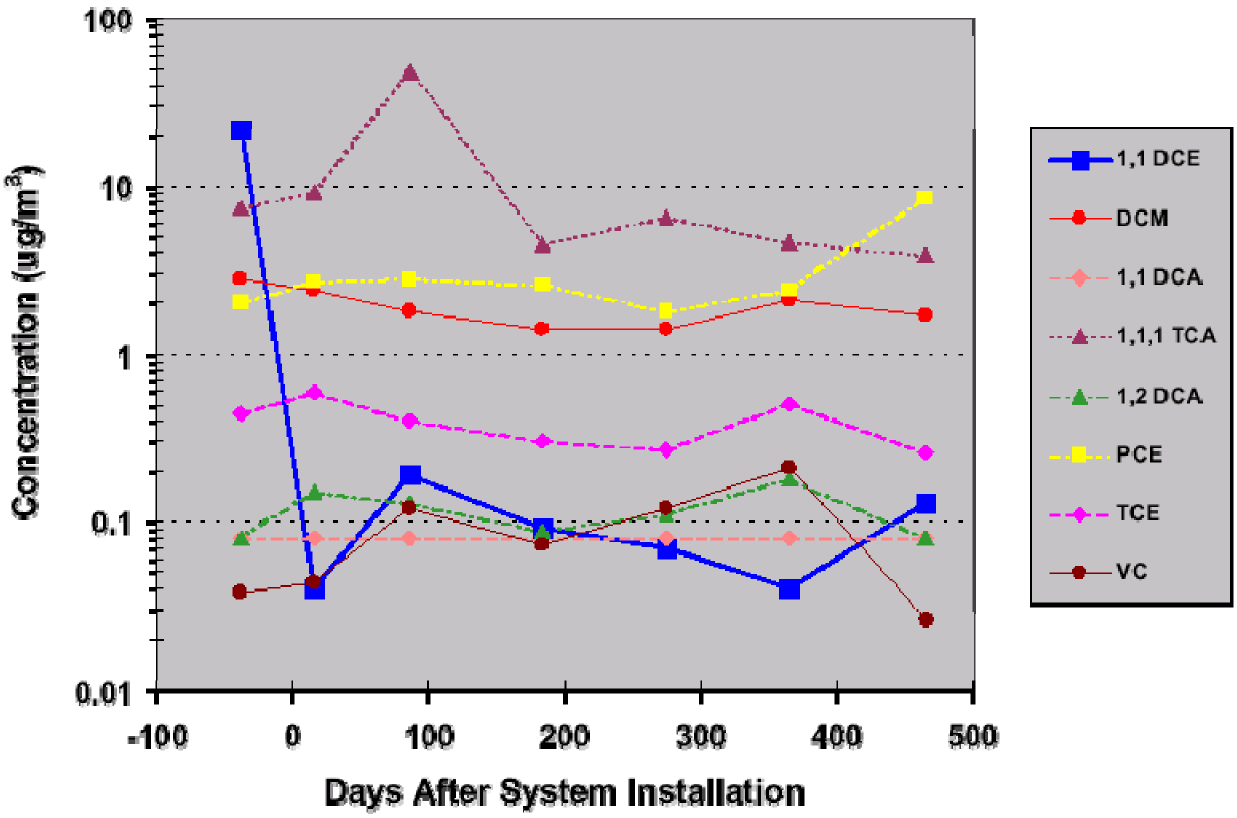


Figure 3. Mitigation system effectiveness evaluation (Folkes, 2000)

Indoor air sampling before and after the installation of a mitigation system was used to evaluate the effectiveness of the mitigation system. The results for 1,1 DCE at this house demonstrate that the mitigation system was working effectively, but indoor air concentrations for all other target compounds were not reduced. The detected concentrations of these compounds were due to background sources. This example illustrates how the use of indoor air data as the sole line of evidence may lead to unnecessary mitigation.

Uncertainty in Use of Indoor Air Concentration Measurements

Dawson and McAlary (2009) and MassDEP (2008) have shown that indoor air samples typically include detectable concentrations of many compounds. Some implications of the effect of background sources on the vapor intrusion pathway evaluation were discussed above. Additionally, background concentrations for several compounds may be at or above risk-based target concentrations (e.g., benzene, carbon tetrachloride, chloroform, and tetrachloroethene). Table 1 shows a comparison of concentrations of chemicals commonly found in indoor air at residences not associated with disposal sites to risk-based indoor air concentrations[1]. Shading indicates that the concentration commonly found in residential indoor air exceeds the risk-based concentration.

Table 1: Background Indoor Air Concentrations v. Risk-Based Concentrations

Compound	50th % Conc. (ug/m^3)	50th % Conc (ug/m^3)	75th % Conc (ug/m^3)	90th % Conc (ug/m^3)	Risk-Based Conc (ug/m^3)
	Dawson and McAlary, 2009	MassDEP, 2008			DRAFT MassDEP, 2008
Benzene	**2.4**	**2.3**	**3.6**	**11**	0.3
Carbon Tetrachloride	**0.5**	**0.54**	**0.62**	**0.86**	0.16
Chloroform	**1**	**1.9**	**2.6**	**3**	0.11
Ethylbenzene	2.2	1.5	2.4	7.4	200
MTBE	0.8	3.5	6.9	39	600
Tetrachloroethene	**0.7**	**1.4**	**2.4**	**4.1**	0.23
Toluene	13	11	21	54	1,000
1,1,1-Trichloroethane	1.8	0.5	1.1	3	1,100
Trichloroethene	0.1	0.29	0.68	0.8	1.4
m/p-Xylene	4	5.9	9.4	**28**	20
o-Xylene	2.2				

Because of the similarity between risk-based indoor air concentrations and typical concentrations found in indoor air unrelated to vapor intrusion, use of measured indoor air concentrations as

[1] Risk-based concentrations are from MassDEP (2008) *Draft Indoor Air Threshold Values for the Evaluation of a Vapor Intrusion Pathway*. Risk-based concentrations are based on a non-cancer hazard index (HI) of 0.2 or an excess lifetime cancer risk (ELCR) of 1 x 10^{-6}. If both a non-cancer and cancer risk-based concentration was available, the lower of the two concentrations is presented.

exposure point concentrations will frequently over-estimate the risk due to vapor intrusion unless the contribution from background sources can be quantified.

Additionally, the temporal variability in indoor air concentrations is well documented. Kuehster et al., 2004 showed that indoor air concentrations of VOCs attributable to vapor intrusion span almost two orders of magnitude (factor of 100) in domestic residences. Rydock et al., 2001 showed that radon concentrations in commercial industrial buildings can show a range of two or three orders of magnitude in response to daily variations in the building ventilation system operations.

As a result, indoor air sampling and analysis seldom provide an accurate and unambiguous indication of long-term average vapor intrusion-related exposures that can be evaluated in risk assessment or clear attribution of the source of the chemicals detected. This does not mean that indoor air sampling is not a useful line of evidence for vapor intrusion evaluation, but it does suggest that it is difficult to use indoor air data as the only data source for this evaluation. For this reason, most current guidance documents for assessing vapor intrusion recommend relying on more than one line of evidence (e.g., ITRC 2007, NYSDEC 2006, NJDEP 2005, and several others). The most common lines of evidence include measuring concentrations of volatile chemicals in soil gas or groundwater beneath or near the building and estimating the indoor air concentration that would be expected using an attenuation factor derived from generic empirical data (e.g., USEPA 2008), mathematical models, or empirical data for tracers (such as radon).

Technically-Defensible Vapor Intrusion Modeling

In order to calculate technically-defensible and sufficiently conservative estimates of indoor air concentrations, it is important to use models that are appropriate for site conditions, use representative source data (i.e., soil gas or groundwater concentration data), and justify model input parameter values.

A range of modeling approaches are available to predict indoor air concentrations based on groundwater or soil gas measurements. Model options include generic empirical attenuation factors (such as the USEPA database), mathematical models (such as the Johnson and Ettinger model), or tracer compounds from site data (such as radon in the example shown in Figure 1). The generic empirical attenuation factors tend to be more conservative but can be biased high due to the impacts of background indoor air sources, as discussed above, and the use of tracer constituents requires detailed analysis of site-specific measurements. The Johnson and Ettinger model may be used either with generic conservative input values or with site-specific inputs.

The use of representative source concentration data for the vapor intrusion modeling is a key input consideration. The input groundwater concentration data should be representative of water-table concentrations; therefore, groundwater samples should be collected from as close as practicable to the water table, using methods that minimize volatilization losses during sampling. Fortunately, groundwater sampling is a relatively mature science, and most consultants use consistent methods. Presently, however, soil gas sampling is conducted less consistently by environmental consultants, and therefore reported soil vapor concentrations may be more susceptible to apparent spatial and temporal variability than reported groundwater concentrations. This has led to a greater uncertainty in soil gas concentrations used in vapor intrusion modeling. There are recent publications that document recommended practices for collecting soil gas samples for vapor intrusion investigations (e.g., API 2005, EPRI 2005, Geoprobe 2006, McAlary and Creamer 2006, McAlary et al. 2009). Incorporating "best practices" identified in this ongoing research into MassDEP's new guidance will help reduce the variability resulting from soil gas sampling techniques and reduce the uncertainty in vapor intrusion modeling results.

Vapor intrusion models may include additional input parameters to characterize soil physical properties and building parameters. Appropriate justification for these input parameters is a necessary component of the modeling process. Typical values for these input parameters are discussed in Johnson, 2005. Additional justification should be provided if site-specific inputs outside the typical ranges reported in this document are utilized in the modeling process.

Conclusions

Based on the information presented above and Geosyntec's experience assessing subsurface vapor transport and intrusion to indoor air, we conclude:

- Vapor intrusion can be assessed using several lines of evidence, each of which has some uncertainty, and none of which are clearly superior for providing an accurate and representative estimate of average indoor air concentrations over a 25 to 30 year exposure scenario; however, use of multiple lines of evidence rather than reliance on a single line of evidence, like measured indoor air data, can help reduce uncertainty and provide understanding of the inherent interference of background concentrations on measured indoor air data.

- In many cases, background sources and temporal variability make it impractical to use measured indoor air concentrations as the sole line of evidence for vapor intrusion assessments. The contribution of background sources to indoor air quality will often result in an over-estimation of vapor intrusion impacts.

- Subsurface sampling and analysis can also be used to estimate indoor air concentrations providing the subsurface data are accurate and representative and that a technically-defensible modeling approach is followed. Several careful studies have shown that empirical or modeled attenuation factors can provide reasonable estimates of indoor air impacts attributable to vapor intrusion, within bounds of uncertainty that are not much different from the uncertainties imposed by indoor air quality variability.

We realize that the development of vapor intrusion guidance for the MCP is a difficult undertaking and we appreciate the opportunity to provide our input into this important process. Flexibility to use multiple lines of evidence and customize the selection of the assessment tools to the site conditions is a common theme among current regulatory guidance for assessing vapor intrusion. We encourage MassDEP to make similar allowances in their forthcoming policies, guidelines and regulatory requirements**.**

If you have any questions or would like additional information, please contact Julianna Connolly or Todd Creamer at 978.263.9588.

Sincerely,

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References:

American Petroleum Institute, 2005. “Collecting and Interpreting Soil Gas Samples from the Vadose Zone: A Practical Strategy for Assessing the Subsurface Vapor-to-Indoor Air Migration Pathway at Petroleum Hydrocarbon Sites.” Publication #4741.

Dawson, H. and T. McAlary, 2009. A Compilation of Order Statistics for VOCs from Post-1990 Indoor Air Concentration Studies in North American Residences Unaffected by Subsurface Vapor Intrusion, Groundwater Monitoring and Remediation 29, no. 1/ Winter 2009/pages 60–69.

EPRI, 2005. Reference Handbook for Site-Specific Assessment of Subsurface Vapor Intrusion to Indoor Air. Technical Report Number 1008492, March.

Geoprobe®, 2006. “Direct-Push Installation of Devices for Active Soil Gas Sampling and Monitoring, Technical Bulletin #3099, May, 2006.

ITRC, 2007. Vapor Intrusion Pathway: A Practical Guideline. January.

Johnson, P. C., R. A. Ettinger, J. Kurtz, R. Bryan, and J. E. Kester. 2002. Migration of Soil Gas Vapors to Indoor Air: Determining Vapor Attenuation Factors Using a Screening Level Model and Field Data from the CDTO-MTL Denver, Colorado Site. API Soil and Groundwater Research Bulletin No. 16. American Petroleum Institute.

Johnson, P.C. 2005. Identification of application-specific critical inputs for the 1991 Johnson and Ettinger vapor intrusion algorithm, Groundwater Monitoring and Remediation, v.25, no.1, pp 63 to 78.

Kuehster, T., D. Folkes & E. Wannamaker, 2004. “Seasonal Variation of Observed Indoor Air Concentrations Due to Vapor Intrusion at the Redfield Site, Colorado,” Midwestern States Risk Assessment Symposium Indianapolis, August 26.

McAlary, T., and T. Creamer, 2006, “The Effects of Purge Rate and Volume on Sub-slab Soil Gas Samples,” A Platform Presentation at the Battelle Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterrey CA, May 2006.

McAlary, T.A., P. Nicholson, H. Groenevelt, and D. Bertrand, 2009. A Case-Study of Soil Gas Sampling in Silt and Clay-rich (Low-Permeability) Materials, Groundwater Monitoring and Remediation, 29, no. 1/ Winter 2009/pages 144–152.

MassDEP, 2008. Residential Typical Indoor Air Concentrations.

MassDEP, 2008. DRAFT Indoor Air Threshold Values for the Evaluation of a Vapor Intrusion Pathway.

NJDEP, 2005. Vapor Intrusion Guidance.

NYSDOH, 2006. Guidance for Evaluating Soil Vapor Intrusion in the State of New York.

Rydock, J.P., A. Nvss-Rolstad, J.T. Brunsell, 2001. Diurnal variations in radon concentrations in a school and office: implications for determining radon exposure in day-use buildings, Atmospheric Environment, v. 35, pp. 2921-2926.

USEPA, 2006. Comparison of Geoprobe® PRT and AMS GVP Soil-Gas Sampling Systems with Dedicated Vapor Probes in Sandy Soils at the Raymark Superfund Site, EPA/600/R-06/111, November.

USEPA, 2006. Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples. EPA/600/R-05/147, March 2006.

USEPA, 2008. U.S. EPA's Vapor Intrusion Database: Preliminary Evaluation of Attenuation Factors – Draft, Office of Solid Waste, U.S. EPA, March.