Barriers to Transfer of Pollutants to Indoor Air

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CETCO

Agenda

- Vapor Intrusion Background
- Vapor Intrusion Barrier Options
- Barrier Diffusion Testing
- US EPA Modified Johnson & Ettinger Risk Model
- Projects
- Summary

Types of vapor risk

- Explosive risk (methane)
- Health risk (volatile organic compounds)
  - Benzene
  - PCE
  - TCE

Interstate Regulatory & Technology Council

- ITRC is a U.S. coalition of personnel from the environmental regulatory agencies of all 50 U.S. states, three federal agencies (U.S. Department of Defense, U.S. Department of Energy and U.S. Environmental Protection Agency), Native American tribes, public and industry stakeholders.
- In 2007 ITRC published a document titled *"Vapor Intrusion Pathway: A Practical Guidance".*
- The Vapor Intrusion document addresses investigating and evaluating the vapor intrusion pathway, including data evaluation and mitigation approaches.
- To download a copy, go to http://www.itrcweb.org.

ITRC Interstate Technology and Regulatory Co

Technical and Regulatory Guidance: Vapor Intrusion Pathway, A Practical Guideline – 2007

www.itrcweb.org/documents/vi-1.pdf

- "The potential for punctures may be reduced by using thicker membranes (e.g., 60–100 mil high-density polyethylene [HDPE] or similar materials); thick layers of spray-on rubberized asphalt emulsions; and cushioning materials above and/or below the membrane..."

Most passive barriers consist of thermoplastic or elastomeric flexible membranes or spray-on rubberized asphalt emulsions. In new structures, barriers are placed beneath the floor slab to prevent subslab soil gas from entering the structure through cracks or construction joints in the slab. In existing structures, membranes can be used to retard the intrusion of vapors in crawl spaces or over dirt floors.

To be effective, passive barriers must provide a complete barrier to vapor intrusion since, by definition, passive barriers do not include any active measures to control the movement of soil gas. Even small imperfections in the barriers (e.g., due to holes, tears, or incomplete seals at the footings or pipe penetrations) may provide a significant migration route for soil gas when buildings are underpressurized. Occupants may accidentally penetrate the barrier as part of general building maintenance. No standard criteria have been developed for minimum passive barrier thickness or physical properties, such as puncture resistance and tear strength. Nevertheless, thin polyethylene films (often called "vapor barriers" because they have been traditionally used to prevent moisture from accumulating behind drywall walls) are easily damaged and are unlikely to survive normal construction abuse, even when cushioned by sand (ASTM 1998). Even thicker (e.g., 10–20 mil) polyvinyl chloride membranes are likely to be damaged during construction, particularly if placed below concrete slabs. Workers are likely to step onto and force aggregate and other sharp objects into the membrane and may actually poke holes into the membrane to encourage water drainage during concrete placement and curing. Studies of flexible membrane liners used for liquid containment in impoundments have shown that even placement of sand and other earth materials is likely to cause a certain amount of puncturing.

The potential for punctures may be reduced by using thicker membranes (e.g., 60–100 mil high-density polyethylene [HDPE] or similar materials); thick (e.g., ¼-inch) layers of spray-on rubberized asphalt emulsions; and cushioning materials above and/or below the membrane, such as geotextiles, sand, or fine rounded gravel (pea gravel). Some proprietary vapor barrier products incorporate cushioning, barrier, and sealing material layers in one material. Nevertheless, no specific criteria have been developed for passive vapor intrusion barriers, and some degree of imperfection (e.g., punctures, incomplete seals at seams and edges) should be expected in virtually all applications. The potential for high concentrations of certain chemicals to adversely impact membrane or solvent seam integrity should also be considered.

Key Elements of Passive Barrier Systems

- Do not expect complete elimination of vapors
- Select barriers that are thick enough to withstand normal construction abuse
- Include thorough quality control procedures to minimize barrier damage
- Inspect barrier seals at all edges, penetrations, and seams
- Test barrier integrity and performance after installation
- Have contingencies to enhance passive barriers if not adequate

In addition to specifying reasonably adequate membrane thicknesses, passive barrier designs should include QA/QC plans that address the potential for damage to the membranes during installation, subsequent concrete pours, and building construction activities and protocols for minimizing such damage. Specifications should require thorough inspection of liner seals along all edges and at penetrations, observation during concrete pouring, and detailed procedures for testing the efficacy of the passive barrier after the slab is placed (e.g., pressure tests, smoke tests,

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- "If only low reductions in vapor intrusion rates are required, passive barriers may be sufficient… the design should allow for the addition of venting… In most cases passive barriers without venting layers are not likely to be effective unless subsurface conditions are conducive to natural venting…Therefore, in most situations, at least passive venting should be combined with passive barriers…"

post-construction indoor air tests). See ASTM Standard E 1643-98 (ASTM 1998) for more information regarding the use of water vapor barriers, although these standards may not be sufficient to address chemical vapor intrusion or associated low indoor air screening levels.

Figure 4-1. Liquid Boot® being applied during construction. Courtesy LBI Technologies, Inc.

Passive barrier designs that rely on complete elimination of vapor intrusion are unlikely to succeed, for the reasons discussed above. If only low reductions in vapor intrusion rates are required, passive barriers may be sufficient; however, some method of measuring the performance of the passive barrier should be specified, and the design should allow for the addition of venting or other measures to address inadequate performance. In most cases, however, passive barriers without venting layers are not likely to be effective unless subsurface conditions are conducive to natural venting. For example, experience shows that in existing structures sealing alone reduces radon levels only 0%–50%, often due to some points of vapor entry that are obscured from view or have no access. Therefore, in most situations, at least passive venting should be combined with passive barriers, as discussed below.

Estimated costs for flexible membranes range \$4–\$50/m^2 (about \$0.50–\$5/ft^2) of building area. Less expensive (and thinner) materials are probably inadequate to be relied on alone as a passive barrier. Spray-on asphaltic emulsions (Figure 4-1) have been installed for \$21–\$32/m^2 (\$2–\$3/ft^2). Price ranges vary based on several factors, including overall area to be covered, number of protrusions that require sealing, and the material used. The barrier thickness and QC measures likely necessary for a passive barrier design to succeed on its own (e.g., without venting) may well result in costs that exceed the ranges quoted above. On the other hand, when passive barriers simply augment other active systems (see below) and are not required to be 100% effective, costs may be closer to the lower end of these ranges.

4.3.1.2 Passive Venting

Passive venting involves the placement of a venting layer below the floor slab to allow soil gas to move laterally beyond the building footprint under natural diffusion gradients (resulting from the buildup of soil gas below the building) or pressure (thermal or wind-created) gradients. Therefore, passive venting is generally feasible in only new construction (see Table 4-3). Because passive venting relies, in part, on soil gas not entering the building before it can vent laterally, passive vents should be combined with passive barriers, as discussed above. Passive venting layers must be permeable enough to allow unimpeded lateral migration of soil gas. Sands or pea gravel (i.e., nonangular materials that will not damage the membrane) are generally preferred below liners. Nonwoven geotextiles with sufficient vapor transmissivity or geogrids may also function as passive venting materials; however, care must be taken to ensure that

Two Types of Gas Vapor Barriers (per ITRC)

Gas vapor barrier options include:

- ≥1.5 mm–HDPE sheet, mechanically fastened and welded

- 1.5 mm Spray-Applied Latex-Asphalt Barrier

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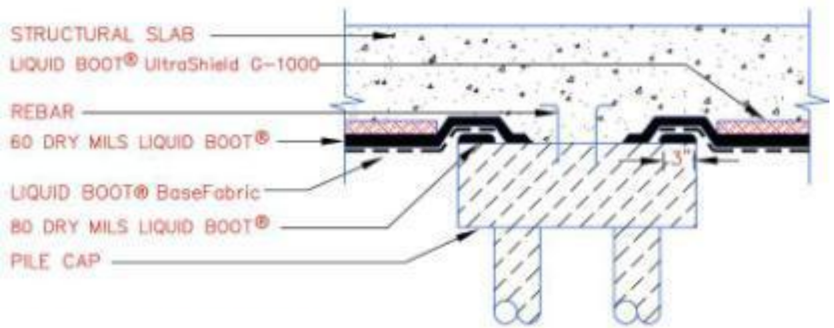
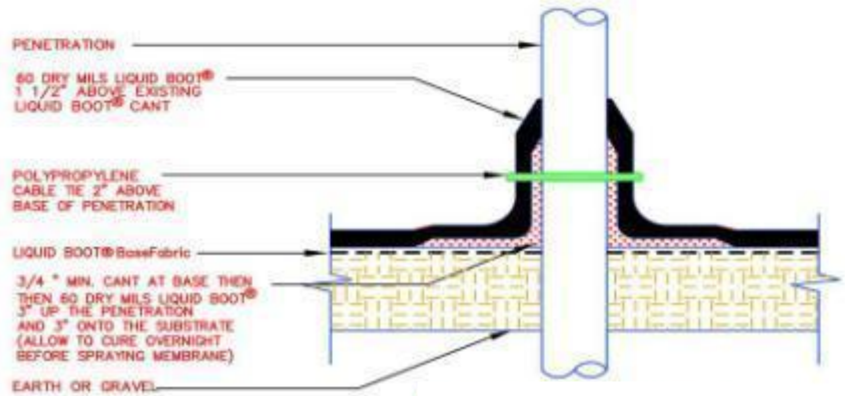
Spray Applied Latex-Asphalt Barrier Details

PILE CAPS AND FOOTINGS

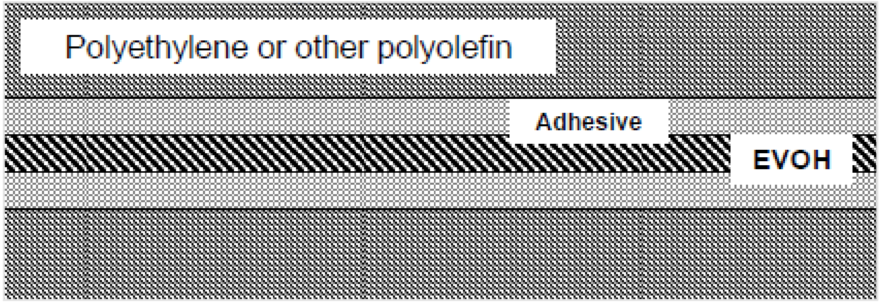


PENETRATIONS



EVOH-LLDPE Barrier Technology

- 0.5 mm barrier with a layer of EVOH between two layers of linear low density polyethylene (LLDPE).
- EVOH is a copolymer of Polyvinyl Alcohol and Ethylene Vinyl Alcohol (provides gas barrier).



- Major applications for EVOH are the food industry and in automotive fuel tanks to control emissions of hydrocarbons
  - The use of EVOH co-extruded with HDPE into fuel tanks originated more than 15 years ago in California in response to mandates by the California Air Resources Board to reduce VOC emissions.

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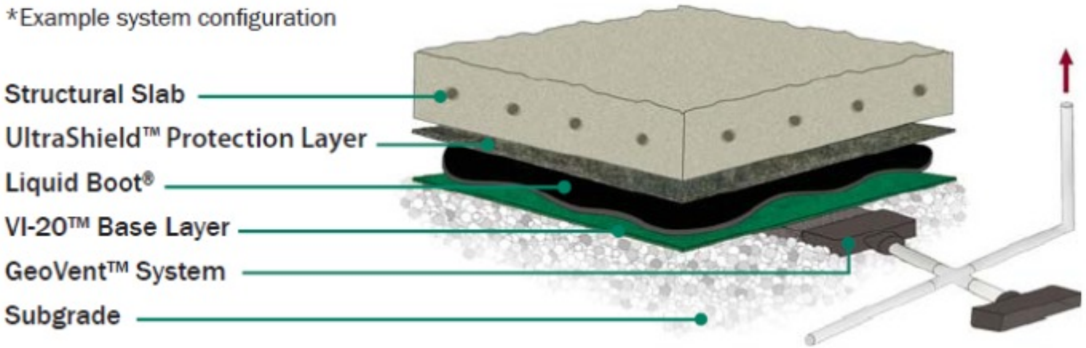
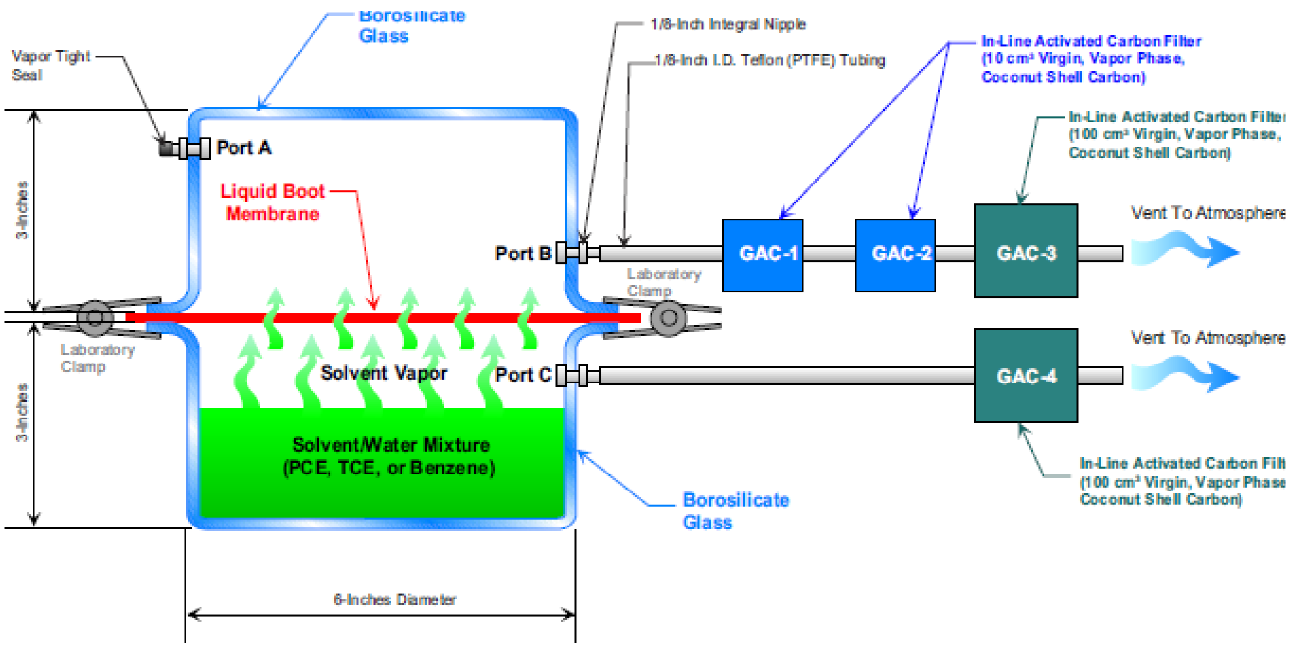
Latex-asphalt sprayed onto LLDPE-EVOH Barrier



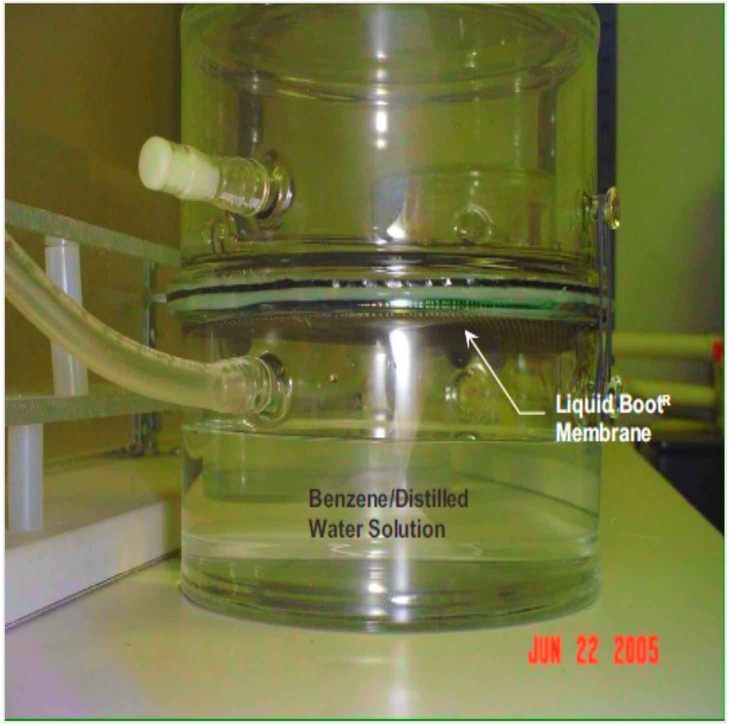
BARRIER VAPOR DIFFUSION TESTS

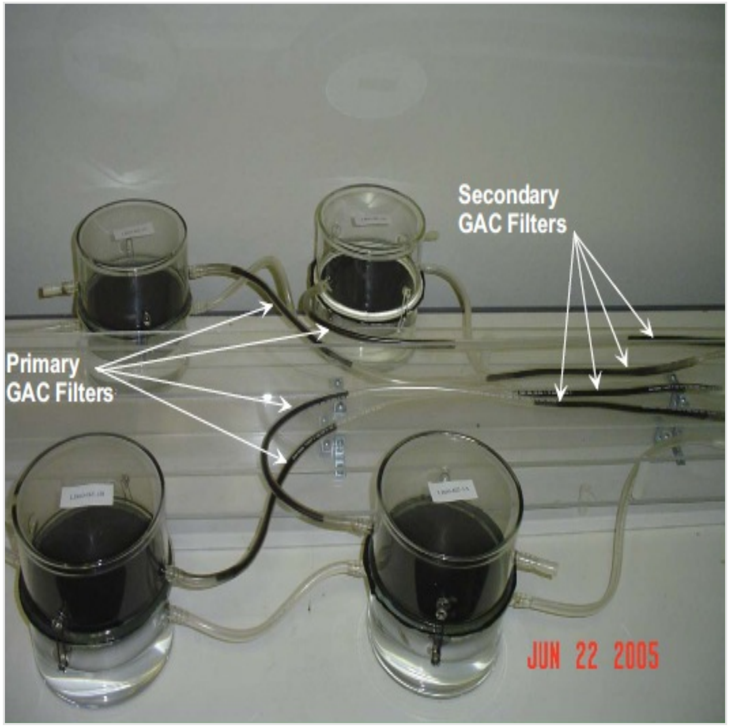
Barrier Vapor Diffusion Test Apparatus

- This diagram from Geokinetics illustrates how the diffusion coefficients on the Liquid Boot barrier for PCE, TCE and Benzene were determined.
- CETCO R&D facility is performing similar tests on Liquid Boot Plus.



Barrier Vapor Diffusion Test Apparatus



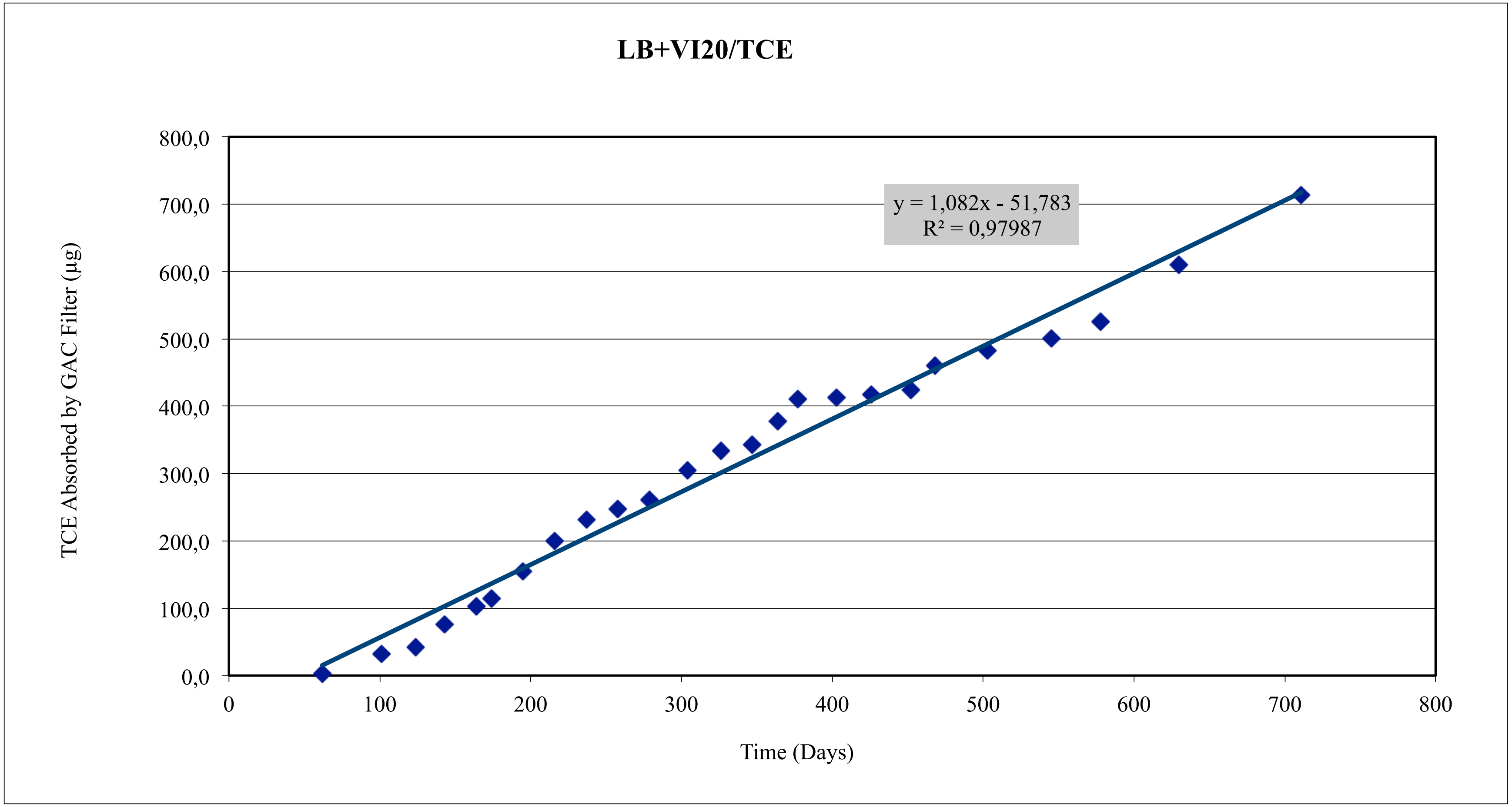


Fick's Law

Applying diffusion test data into the Fick's Law equation results in the diffusion coefficient:

$$E = A(C_{source} - C_{g0})D_{czeff} / L_{cz}$$

where	E	=	Rate of mass transfer, g/s
	A	=	Cross-sectional area through which vapors pass, cm^2
	C_{source}	=	Vapor concentration within the capillary zone, g/cm^3-v
	C_{g0}	=	A known vapor concentration at the top of the capillary zone, g/cm^3-v (C_{g0} is assumed to be zero as diffusion proceeds upward)
	D_{czeff}	=	Effective diffusion coefficient across the capillary zone, cm^2/s
	L_{cz}	=	Thickness of capillary zone, cm


LB+VI20/TCE
y = 1,082x - 51,783
R² = 0,97987
TCE Absorbed by GAC Filter (µg)
800,0
700,0
600,0
500,0
400,0
300,0
200,0
100,0
0,0
0
100
200
300
400
500
600
700
800
Time (Days)

Composite Barrier Diffusion Test Results

Test Conditions	Average Solvent Diffusion Rate	Membrane Area	Membrane Thickness	Calculated Diffusion Coefficient
PCE Solvent @ 120,000 mg/m^3	0.029 ug/day	1.45×10^{-2} m^2	2.03×10^{-3} m	3.1×10^{-16} m^2/sec
TCE Solvent @ 524,000 mg/m^3	1.08 ug/day	1.45×10^{-2} m^2	2.25×10^{-3} m	3.0×10^{-15} m^2/sec

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USEPA Risk-Based Vapor Intrusion Models

US EPA Modified Johnson & Ettinger VI Model

- US EPA has a risk-based vapor intrusion model available @: www.epa.gov/oswer/riskassessment/airmodel/johnson_ettinger.htm

- The model includes:
  - A 3-phase soil contamination model that theoretically partitions the contamination into three discrete phases: 1) in solution in ground water, 2) sorbed to the soil organic carbon, and 3) in vapor phase within the soil air-filled pores.
  - Two additional soil gas models allow the user to input measured soil gas concentration and sampling depth data directly into the spreadsheet.
  - A NAPL model, for cases when NAPL is present in soils, allows including contamination in a fourth or residual phase.

Soil Gas Model Worksheet

Soil Gas Concentration Data

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Soil gas conc., C_g ($\mu g/m^3$)	OR	ENTER Soil gas conc., C_g (ppmv)	Chemical
79016			5.24E+02	Trichloroethylene

ENTER Depth below grade to bottom of enclosed space floor, L_F (cm)	ENTER Soil gas sampling depth below grade, L_s (cm)	ENTER Average soil temperature, T_S (°C)	ENTER Totals must add up to value of Ls (cell F24) Thickness of soil stratum A, h_A (cm)	ENTER Thickness of soil stratum B, (Enter value or 0) h_B (cm)	ENTER Thickness of soil stratum C, (Enter value or 0) h_C (cm)	ENTER Soil stratum A SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined stratum A soil vapor permeability, k_v (cm^2)
15	15.2	10	15.2	30	60			1.00E-12

ENTER Stratum A SCS soil type	ENTER Stratum A soil dry bulk density, ρ_b^A (g/cm^3)	ENTER Stratum A soil total porosity, n^A (unitless)	ENTER Stratum A soil water-filled porosity, θ_w^A (cm^3/cm^3)	ENTER Stratum B SCS soil type	ENTER Stratum B soil dry bulk density, ρ_b^B (g/cm^3)	ENTER Stratum B soil total porosity, n^B (unitless)	ENTER Stratum B soil water-filled porosity, θ_w^B (cm^3/cm^3)	ENTER Stratum C SCS soil type	ENTER Stratum C soil dry bulk density, ρ_b^C (g/cm^3)	ENTER Stratum C soil total porosity, n^C (unitless)	ENTER Stratum C soil water-filled porosity, θ_w^C (cm^3/cm^3)
C	1.43	0.459	0.215	C	1.43	0.459	0.215	C	1.43	0.459	0.215

ENTER Enclosed space floor thickness, L_{crack} (cm)	ENTER Soil-bldg. pressure differential, ΔP ($g/cm\text{-}s^2$)	ENTER Enclosed space floor length, L_B (cm)	ENTER Enclosed space floor width, W_B (cm)	ENTER Enclosed space height, H_B (cm)	ENTER Floor-wall seam crack width, w (cm)	ENTER Indoor air exchange rate, ER (1/h)		ENTER Average vapor flow rate into bldg. OR Leave blank to calculate Q_{soil} (L/m)
10	40	1000	1000	366	0.1	0.25		5

ENTER Averaging time for carcinogens, AT_C (yrs)	ENTER Averaging time for noncarcinogens, AT_{NC} (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
70	30	30	350

Soil Gas Worksheet with Barrier Diffusion Coefficient

Exposure duration, τ (sec)	Source-building separation, L_T (cm)	Stratum A soil air-filled porosity, θ_a^A (cm^3/cm^3)	Stratum B soil air-filled porosity, θ_a^B (cm^3/cm^3)	Stratum C soil air-filled porosity, θ_a^C (cm^3/cm^3)	Stratum A effective total fluid saturation, S_{te} (cm^3/cm^3)	Stratum A soil intrinsic permeability, k_i (cm^2)	Stratum A soil relative air permeability, k_{rg} (cm^2)	Stratum A soil effective vapor permeability, k_v (cm^2)	Floor-wall seam perimeter, X_{crack} (cm)	Soil gas conc. ($\mu g/m^3$)	Bldg. ventilation rate, $Q_{building}$ (cm^3/s)
9.46E+08	0.2	0.244	0.244	0.244	#N/A	#N/A	#N/A	1.00E-12	4,000	2.96E+06	2.54E+04

Area of enclosed space below grade, A_B (cm^2)	Crack-to-total area ratio, η (unitless)	Crack depth below grade, Z_{crack} (cm)	Enthalpy of vaporization at ave. soil temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. soil temperature, H_{TS} ($atm\text{-}m^3/mol$)	Henry's law constant at ave. soil temperature, H'_{TS} (unitless)	Vapor viscosity at ave. soil temperature, μ_{TS} (g/cm-s)	Stratum A effective diffusion coefficient, D^{eff}_A (cm^2/s)	Stratum B effective diffusion coefficient, D^{eff}_B (cm^2/s)	Stratum C effective diffusion coefficient, D^{eff}_C (cm^2/s)	Total overall effective diffusion coefficient, D^{eff}_T (cm^2/s)	Diffusion path length, L_d (cm)
1.06E+06	3.77E-04	15	8,557	4.78E-03	2.06E-01	1.75E-04	3.00E-11	3.24E-03	3.42E-03	3.00E-11	0.2

Convection path length, L_p (cm)	Source vapor conc., C_{source} ($\mu g/m^3$)	Crack radius, r_{crack} (cm)	Average vapor flow rate into bldg., Q_{soil} (cm^3/s)	Crack effective diffusion coefficient, D^{crack} (cm^2/s)	Area of crack, A_{crack} (cm^2)	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, α (unitless)	Infinite source bldg. conc., $C_{building}$ ($\mu g/m^3$)	Unit risk factor, URF $(\mu g/m^3)^{-1}$	Reference conc., RfC (mg/m^3)
15	2.96E+06	0.10	8.33E+01	3.00E-11	4.00E+02	#NUM!	6.26E-09	1.85E-02	1.1E-04	4.0E-02

END

CASE STUDY PROJECT

El Centro Medical Clinic

Former automotive facility; TCE vapors in soil gas

VI-20™ LLDPE-EVOH barrier deployment

Liquid Boot™ polychloroprene latex-asphalt emulsion being spray applied

Summary

- Vapor intrusion should be evaluated for sites with potential hazardous or carcinogenic vapors.
- ITRC has provided guidance on vapor mitigation options.
- A new vapor mitigation barrier system utilizes the benefits of both a polyethylene barrier and a spray-applied latex-asphalt barrier.
- Vapor diffusion test results show low vapor diffusion coefficients for this composite barrier.
- US EPA has vapor intrusion models available that can be used to determine vapor risk, with and without a barrier.

Merci!

Presenter

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