DoD Vapor Intrusion Handbook
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Use of Tracers, Surrogates, and Indicator Parameters in Vapor Intrusion Assessment

Purpose

This fact sheet, which was prepared by the Department of Defense (DoD) Tri-Services Environmental Risk Assessment Workgroup (TSERAWG), relates to Sections 2.1, 3.5 and 3.3.5 and Appendices G, H and I of the DoD Vapor Intrusion Handbook and reflects the application of new technologies for vapor intrusion (VI) sampling.

Introduction

VI assessments can be improved using tools that help guide investigations or clarify the processes or mechanisms affecting vapor transport. Tracers are substances that migrate similarly to the volatile organic compounds (VOCs) of interest for VI. Indicators are parameters or variables that are associated with the potential for VOC exposures through VI. Surrogates are variables with a quantitative relationship to the target VOCs for a VI study, sufficient to be useful as a substitute for directly measuring the target compounds. Tracers or surrogates may be compounds seldom found in consumer products or building materials, which reduces the potential for positive bias by background sources of the VOCs not from VI.

Potential Advantages

Tracers, surrogates, and indicators can be used for several purposes as part of a VI assessment to:

- Guide the location or timing of sample collection to reduce the risk of unrepresentative data attributable to spatial or temporal variability in VOC vapor concentrations;
- Develop building-specific attenuation factors (ratio of indoor air concentration divided by sub-slab concentration) for estimating indoor air VOC levels from subsurface vapor concentration data;
- Resolve the relative contributions of VI and background sources on indoor air VOC concentrations;
- Support risk assessments by reducing the potential for low-biased exposure estimates;
- Demonstrate VI mitigation system performance and effectiveness;
- Provide quality assurance/quality control (e.g., leak checks);
- Estimate building ventilation system characterization, such as air exchange rate (AER), mixing between zones, trends between occupied and unoccupied periods, etc.;
- Characterize vapor transport below, within, or across building envelopes to aid in the understanding of baseline VI or mitigation system performance; and
- Provide information on temporal variability of VI processes, which may not be cost effectively observed by direct measurement.

Potential Limitations

- The degree to which tracers, surrogates or indicators are correlated to VI or help predict VI may vary from place to place and time to time.
- The correlation between surrogates, tracers or indicators and VI may require effort to characterize for some buildings and can be costly; and
- Some tracers may have practical constraints (e.g., sulfur hexafluoride [SF_6] is a greenhouse gas and faces regulatory constraints, helium [He] is buoyant at high concentrations, thoron is very short-lived, the average outdoor radon concentration in the United States is 0.4 pCi/L (NAS, 1999) which is not negligible compared to indoor air concentrations in most homes, so the contribution from the subsurface may be difficult to discern).

Keys to Data Quality

- Correlation between surrogates, tracers or indicators and VOCs over time and space needs to be understood to some degree to support their application for VI assessment.
- For tracers, the behavior will only mimic VOCs if their distribution and transport properties are similar or the differences are understood well enough to be interpreted. For example: radon is not distributed the same as VOCs in the subsurface and has a relatively fast decay rate compared to the subsurface migration rates, so it will behave somewhat differently than VOCs.
- Radon will be most useful in areas where the subsurface radon concentration is elevated and where radon concentrations in outdoor air are low compared to indoor air;
- Care is needed for selection of appropriate tracers (e.g., perfluorocarbon [PFCs], chlorofluorocarbons [CFCs], SF_6, He, carbon dioxide [CO_2]) and analytical methods (consider sensitivity, interference, density, turn-around time, cost, precision, and accuracy), instrument calibration and maintenance, tracer delivery (pulse versus continuous, local versus distributed), and rate of data capture (frequency of measurement).
- Inter-method checks are valuable if both field and laboratory data are collected.
- Inter-instrument checks are valuable if multiple field instruments are used.
- Sufficient duplicate samples should be included to verify precision.

Rationale for Use of Tracers, Surrogates, and Indicators

Data collected from detailed VI assessments indicate that spatial and temporal variability result in a potential risk of failing to identify representative or near worst-case exposure conditions when a small number of indoor air samples are collected using conventional 8- or 24-hour duration time-weighted average samples. For chronic risks, samples can be collected over a longer duration to minimize the impact of temporal variability (see fact sheet on passive samplers [link to TSERAWG 2017]). However, for risks from acute exposures, it is important to understand near worst-case concentrations over shorter durations which can be achieved by either large numbers of measurements or strategically making measurements at locations and times when near worst-case conditions would be expected to occur, if they are knowable. Tracers, surrogates, and indicators can be used to guide the selection of the location and time of sample collection, potentially to reduce the number of samples and cost and achieve an equal or greater level of confidence despite the spatial and temporal variability challenges associated with VI assessments.

The concept of near worst-case is also relevant spatially. A site may have numerous buildings and large buildings may have multiple heating, ventilation, and air conditioning (HVAC) zones, each of which can constitute exposure units in many cases. For example, in a large warehouse with an office wing, certain workers may be primarily present in the office space, which may be separately heated/cooled. Indicators, tracers and surrogates can assist in locating which buildings or zones may be most vulnerable to VI.

Tracers, surrogates, and indicators can also help to understand the processes and mechanisms that are important for a given building or site, including cause and effect relationships, fate and transport mechanisms, and building features such as atypical preferential pathways. These are often important for developing a conceptual site model to enable reasonable interpretation of vapor concentrations between and beyond sample locations, and future forecasts from current conditions.

Example Surrogate: Radon

For sites where a large number of buildings are under consideration for a VI assessment, radon monitoring may help to identify buildings that are more susceptible to VI and guide the selection of buildings for VOC sampling. Radon monitoring over time may also help to guide selection of the time of day or time of year that may represent a near worst-case condition. Radon concentrations in sub-slab and indoor air can be monitored with small electronic instruments that are relatively inexpensive. Very inexpensive time-integrated measurements of radon are also available. The ratio of radon in indoor air to radon in sub-slab soil gas can be used as an indication of the building-specific attenuation factor for VOCs (McHugh et al., 2008), although there may be cases where the spatial distributions of VOCs and radon are dissimilar enough to render this unreliable. More information on radon sampling and analysis is described in U.S. EPA (1992, 1993), Mosley et al. (2010), and Lutes et al. (2010).

As an example of the correlation between radon and VOCs in indoor air, Figure 1 shows data collected for both parameters in the research house owned by Arizona State University (known as Sun Devil Manor) near Hill Air Force Base as part of Strategic Environmental Research and Development Program (SERDP) Project ER-1686.

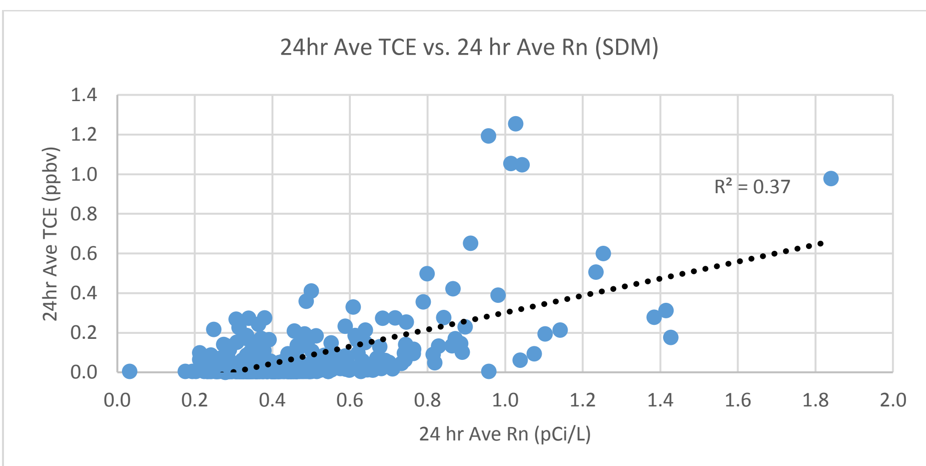

Figure 1: Indoor air TCE versus Radon at Sun Devil Manor (Kurtz, 2017)

There is a positive correlation, but the correlation coefficient is only 37%. However, radon concentrations above 0.8 pCi/L in indoor air are associated with the highest observed indoor air trichloroethene (TCE) concentrations and no TCE concentrations above 0.5 parts per billion vapor (ppbv) were observed with radon concentrations below 0.8 pCi/L. Outdoor air radon concentrations are commonly above 0.2 pCi/L, so many of the radon measurements in indoor air may be attributable to ambient outdoor air with no significant contribution from VI. Radon would likely be most useful in areas where the indoor air concentration is much higher than the outdoor air concentration.

Another detailed study of VI and radon was conducted by the U.S. EPA at a house in Indianapolis (U.S. EPA, 2012). The study found that radon and VOCs were positively cross-correlated at several indoor air sampling locations at a 5% critical level (i.e., radon and VOC concentrations in indoor air increase together for the most part). However, radon would not have completely predicted VOC VI over all time scales.

Example Indicator: Temperature (Difference between Indoor versus Outdoor)

Thermal convection occurs when the temperature of air inside a house is different than outside. During the heating season, hot air inside a building rises, and causes positive pressure at the top and negative pressure at the bottom, which is referred to as the stack effect[1]. The magnitude of the pressure changes depends on the height of the building and the temperature difference between indoor air and outdoor air. Thus, tall buildings in cold climates can have a greater potential for VI. The stack effect can enhance VI, particularly when outdoor temperatures are below freezing, which indicates a reasonable maximum exposure (RME) condition is more likely to be encountered in winter months for buildings in cold climate areas. For example, the TCE indoor air concentrations at Sun Devil Manor were elevated most when the indoor air temperature was more than 20 ^{o}C higher than outdoor air temperature as shown in Figure 2.

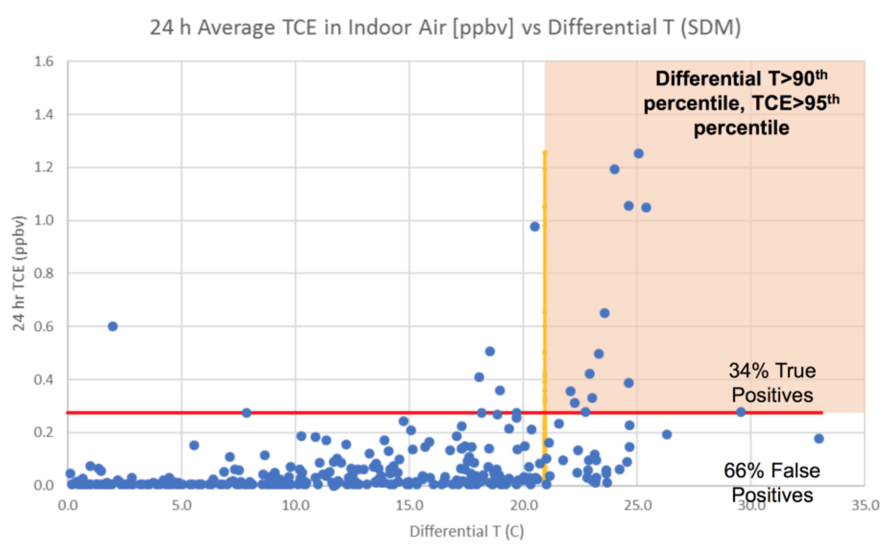

Figure 2: Indoor air TCE concentrations versus indoor air to outdoor air temperature differential (Kurtz, 2017)

There are areas where the outdoor air temperature is higher than the indoor air temperature and the effect could be reversed, creating a positive pressure in the lower floors of the buildings (Mijorski and Cammelli, 2016). There are also areas where the effect would be minimal because of a moderate and relatively consistent climate. Building mechanical engineers can often provide useful information about building pressures and the influences of thermal gradients, as well as air supply fans and exhaust fans. When practical to collect, pressure measurements are useful and provide complementary information.

[1] A similar "solar stack effect" can occur in other seasons when a building heated naturally by the sun during the day stays warm during a cool night.

Example Indicator: Building Pressure

VI is promoted when the building is under a negative pressure compared to the subsurface. This can be induced by using fans to draw air from the building ([link to TSERAWG 2017b], [SERDP ER-1686], Environmental Security Technology Certification Program (ESCTP) [ER-201119], and [ESTCP ER-201503]). Alternatively, the ambient pressure differential can be monitored over the duration of an indoor air sampling event and the data can be reviewed after the sample is collected to assess whether the pressure gradients would likely have favored an RME condition (mostly negative), or not (mostly positive pressure), or worse case or acute exposure (always negative). Samples collected under predominantly positive building pressure may not represent an RME condition.

As an example of the relationship between building pressure and indoor air concentrations, Figure 3 shows indoor air concentrations reported for TCE at a site where high subsurface concentrations were measured and a high-frequency indoor air quality monitoring program was performed (Hosangadi et al., 2017). For the subset of data where the sub-slab pressure was greater than indoor air pressure (positive values on Figure 3), the correlation coefficient was 60%, and the correlation was positive (increasing TCE concentration with increasing pressure differential).

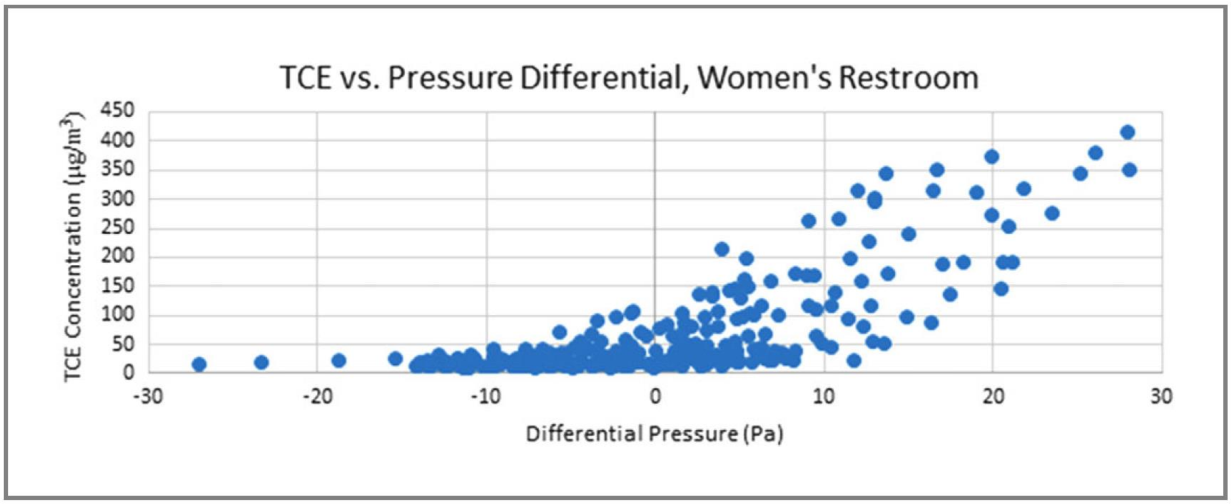

Figure 3: Indoor air TCE versus cross-slab pressure differential (positive values indicate sub-slab region had higher pressure than indoor air) (Reprinted from Hosangadi et al., 2017 with permission John Wiley and Sons)

Example Indicator: Sub-slab PID or Flame Ionization Detector Readings

Locations most likely to have RME conditions in indoor air can often be identified by screening sub-slab vapors using a photoionization detector (PID) for chlorinated compounds or flame ionization detector (FID) for hydrocarbons [link to TSERAWG 2017c]. These instruments must be properly calibrated prior to use and checked periodically during use, but can identify vapor concentrations as low as about 0.1 parts per million by volume (ppmv) and up to about 10,000 ppmv. Buildings with VI at levels that pose unacceptable risks usually have subsurface vapor concentrations within this range. A PID or FID is not usually sensitive enough for indoor air quality monitoring, in which case a portable or transportable gas chromatograph (GC) with a mass spectrometer (MS) or electron capture detector (ECD) or a Fourier transform infrared (FTIR) spectrometer could be used. An FID or PID provides useful real-time sub-slab data to guide sample collection for more detailed laboratory analysis, which is required to identify which specific compounds are present and their relative proportions (PID and FID data provide total VOC responses only). A PID or FID can also be used to screen floor drains, perimeter cracks, expansion joints, or other discontinuities in the floor, particularly if the building is depressurized to promote VI to assess potential preferential pathways for vapor entry to the building.

As an example, Figure 4 shows the results of collocated measurements made with a PID (ppbRAE by RAE Systems) and the trace atmospheric gas analysis (TAGA) unit of the U.S. EPA (a mobile dual quadrapole mass spectrometer) at the Ertel site in Indianapolis as part of a soil vapor sampling demonstration at the Midwestern States Risk Assessment Symposium (MSRAS) in 2006. For 32 paired measurements, the slope of the regression was 0.98 and the correlation coefficient was 97%. Individual chemicals quantified by the TAGA were multiplied by the response factor for the PID and summed to provide a total VOC reading directly comparable to the PID. The correlation was strong in the range of 1 to 100 ppm. For TCE, the dominant compound at the site, this corresponds to a range of about 3,400 to 340,000 $\mu g/m^3$. (1 ppm x 0.62 response factor x 131.4 g/mole ÷ 24.4 L/mole molar volume x 1,000 L/m^3). For an indoor air TCE screening level of 3 $\mu g/m^3$ (worker exposure scenario and lifetime incremental cancer risk of one in a million) and a typical commercial attenuation factor (generally in the range of 0.001 to 0.00001[2]), the sub-slab screening level would be in the range of 3,000 to 300,000 $\mu g/m^3$, so the PID would provide adequate sensitivity to identify sub-slab areas of potential concern for VI.

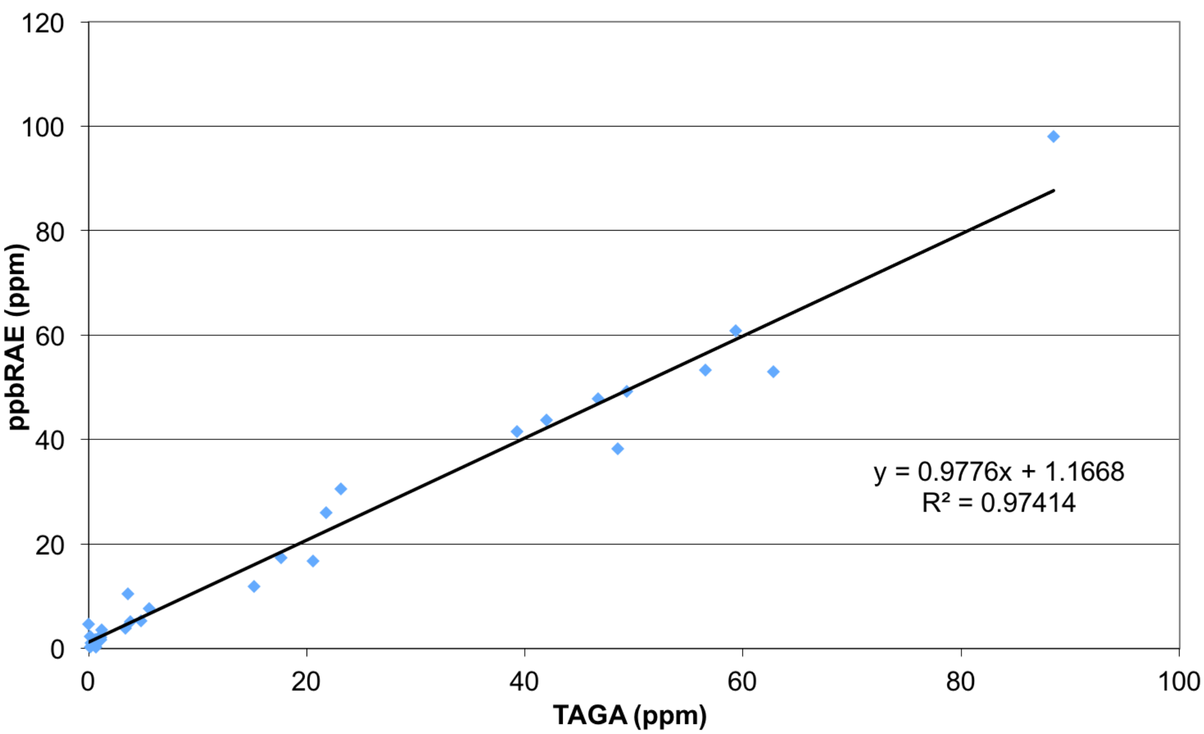

Figure 4: ppbRAE reading versus TAGA mass spectrometer for soil vapor samples (MSRAS, 2006)

[2] NESDI has compiled a database of sub-slab to indoor air attenuation factors for commercial buildings, which is not yet published.

Example Tracer: Perfluorocarbon (PFC) Emitters in Sewer Pipes

In some buildings, sanitary sewers, storm sewers, land drains, and other subsurface utilities with open pipes may create a potential preferential pathway to the region below a building or directly to indoor air. Quantifying the contribution of sewer gas to indoor air can be challenging. ESTCP Project ER-201505 consists of performing tests with passive emitters (permeation tubes filled with a liquid tracer that releases vapors at an essentially constant rate) and passive samplers (sorbent samplers that collect vapors released by the emitters) with a goal of demonstrating and validating field testing protocols that can identify whether gas within the subsurface pipes is entering indoor air in significant proportions (McHugh et al., 2017). PFCs are well suited for use as tracers in this application because they can be detected at very low levels using sensitive analytical instruments, and are present in the atmosphere at very low background levels (i.e., <1 to 9 parts per quadrillion). Different PFCs can be released at each emitter location and several locations can be selected to distinguish intrusion from different utilities or locations within a utility. PFC sampling and analysis methods developed by Brookhaven National Laboratory are suitable for the sampling and analysis (Dietz and Cote, 1982; Dietz et al., 1986). Tests would generally be conducted over a period of a few days to assess the time-weighted average ratio of concentrations inside buildings divided by concentrations measured in the utility (the utility attenuation factor), which would be multiplied by VOC concentrations measured in the headspace of the sewer to estimate the component of VOC VI attributable to sewer gas flow into the building.

In some cases, odor could also be used as an indicator of times when sewer gas is contributing to indoor air concentrations. Odor itself is not an indicator of toxicity, but sewer gas often contains mercaptans and other substances with a low odor threshold which allows observations of sewer gas odor to help guide the application of other assessment methods.

Example Tracer: Building Air Exchange Rate

Building air exchange rate (AER) contributes to dilution of vapor concentrations entering from the subsurface, and is an important component of the attenuation of vapor concentrations. There is variability depending on the relative magnitudes of passive infiltration and forced ventilation, temperature, wind speed, barometric pressure, occupant's activities, and ventilation system design and operation. Understanding the short-term variation in air exchange rates is useful for assessing short-term (acute) exposures, and averaging the temporal variability is helpful for assessing long-term (chronic) exposures. Several types of tracer tests can be used to measure air exchange rates (ASTM E741-11, U.S. EPA IP-4A&B):

1. Pulse Release:
    a. Release a fixed amount of tracer and mix, then monitor decay in concentration over time.
    b. AER = $(\ln C_2 - \ln C_1)$/(delta t)
2. Continuous Release:
    a. Release tracer at a fixed rate of mass per unit time [M/t]
    b. Indoor air concentrations increase and eventually stabilize at a concentration (C) that depends on the volume (V) and AER
    c. AER = (M/t)/C
3. Constant Concentration:
    a. Release tracer at a measured and adjustable rate to sustain a constant concentration in indoor air

b. Similar to continuous release, but also provides information regarding changes in AER over time (also more expensive, so seldom used).

Background tracers may also be used to measure air exchange rates. For example, the concentrations of carbon dioxide (CO_2) and the number of people inside a given volume of a building can be used to calculate the AER because there is a certain predictable CO_2 production rate per person. If the total AER is known, the percentage of outdoor air (%OA) can be estimated from CO_2 or temperature measurements (TSI, 2013).

$$\%OA = (X_R - X_S)/(X_R - X_O) \times 100\%$$

where:
X_R = Return air CO_2 concentration OR temperature
X_S = Supply air CO_2 concentration OR temperature
X_O = Outdoor air CO_2 concentration OR temperature

Blower door testing can also be used to estimate air exchange rates (ASTM, 1991; United States Army Corps of Engineers [USACE], 2012). A blower door is used to impose a large pressure differential and measure the flow of outdoor air required to achieve that pressure, from which the building envelope leakage can be calculated. These tests are performed to measure the flow rates required to achieve several different levels of pressure in the building and the AER is calculated from the flow/pressure ratio and the monitored differential pressure under ambient conditions.

Example Tracer: Mitigation System Testing

VI mitigation systems generally follow guidance for radon mitigation systems which focus on measuring vacuum below a floor and verifying indoor air concentrations below target levels after the system has been operating for a few days. This approach is under review and alternatives are being drafted by a committee of the American National Standards Institute (ANSI) and American Association for Radon Scientists and Technicians (AARST) (ANSI/AARST, 2015). Furthermore, there is debate whether VOCs and radon behave sufficiently differently to justify somewhat specific approaches for both classes of compounds.

Sub-slab depressurization (SSD) or sub-slab ventilation (SSV) systems typically involve removing gas from below a floor slab using a fan and discharging through a pipe to a certain height above the roofline. The radius of influence of each suction point extends to a certain distance, within which the leakage of air across the floor equals the volume of gas withdrawn by the fan. Therefore, assessing the rate of leakage across the floor is important for understanding the spacing required between suction points, which influences the cost of the system.

1. Cross-Floor Leakage via Tracer Release to Indoor Air:
    a. Release tracer into indoor air and measure tracer concentration after mixing, then turn on mitigation system and monitor tracer concentration in vent pipes
    b. Tells proportion of indoor air drawn through the venting system, which indicates energy losses and potential benefit of sealing floor
    c. Use in combination with mass flux monitoring from vent pipes to assess whether optimal operation can be achieved at lower flow rates.
2. Cross-Floor Leakage via Natural Subsurface Tracers:
    a. Monitor O_2, CO_2 and CH_4 in vent pipes over time at the start of operations of a sub-slab venting system.
        i. If O_2 <21%, CO_2 >0.1% or CH_4 > 3 ppm, then soil gas shows signs of biological activity (common where there are petroleum hydrocarbons in the subsurface).

ii. Leakage of indoor air across the floor will result in changes in concentrations of fixed gases toward atmospheric levels – rate of change indicates whether leakage rate across the floor is high or low.

3. Sub-slab Velocity via Helium Flood Test:

   Current building codes usually specify granular fill below a concrete floor slab, and modern buildings are often compliant, so highly permeable material is often present below floor slabs, which can transmit high rates of soil gas flow with minimal vacuum. In this case, the mitigation system can operate as a sub-slab ventilation system instead of a sub-slab depressurization system. Direct measurements of the horizontal velocity below the floor can provide verification that the mitigation system performance extends beyond the radius of a certain vacuum level, which can be used to develop more cost-effective mitigation system designs. The helium flood test consists of blowing air into the subsurface with 1% helium added, and if helium is detected at concentrations approaching 1% in a sub-slab probe at some distance, the radius of influence extends at least that far, even if the pressure at that radius is too low to measure. The average travel time is the time required for the concentrations to reach 50% of the injected concentration (i.e., 0.5% or 5,000 ppmv).

As an example, Figure 5 shows data from a helium flood test in a residence at a flow rate of about 100 standard cubic feet per minute (scfm), with a helium concentration of 0.8% v/v (8,000 ppmv), and a monitoring point at a distance of 12 feet from the point of suction.

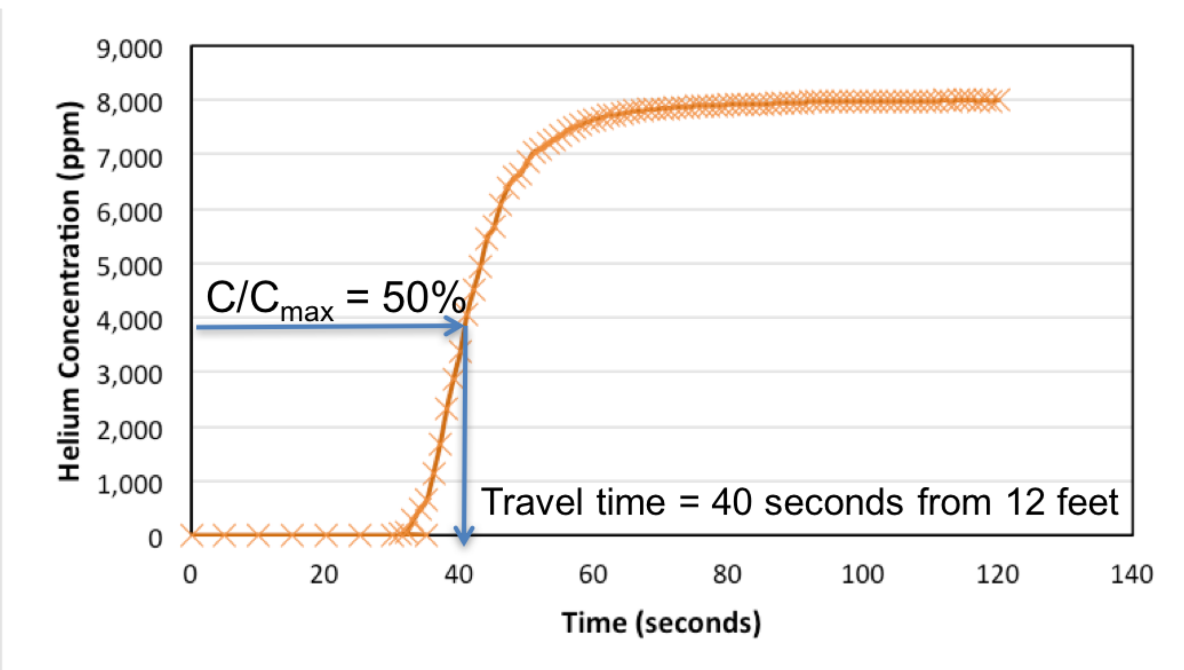

Figure 5: Results of a helium flood test showing travel time of 40 seconds to a radial distance of 12 feet from the suction pit, where air was injected temporarily at 100 scfm (Courtesy of Geosyntec)

Tracer Selection

Tracers should be safe (non-toxic, not explosive, not asphyxiants), conservative (does not react, transform, degrade, sorb, dissolve, etc.), neutrally buoyant, with limited analytical interferences, adequate instrument sensitivity, limited background, and no significant concern with greenhouse gas emissions, or health risks to workers conducting tracer tests. Not all tracers have these characteristics and different tracer tests have different requirements, so it is useful to have a range of options.

Density effects are proportional to molecular weight and concentration, so it is best to use dilute tracers to avoid density-driven flow. SF_6 (heavy) can be diluted to very low concentrations because the analytical methods are very sensitive. Helium (light) needs to be used at higher concentrations to be detected, but also diffuses and therefore dilutes very rapidly, and density is important only at relatively high concentrations. Density-driven advection depends on both the density contrast of the tracer in air compared to normal air, but also the gas permeability of the material through which the tracer is flowing. So, for example, in the helium flood, the density of air with 1% He is about 1.19 g/L instead of 1.2 g/L for typical air. This will cause a small buoyant effect, but if the gas is injected under the floor slab, upward flow through concrete will be limited because concrete has a very low gas permeability.

Some tracers do not need to be added because they are always being emitted from subsurface sources or building materials (e.g., radon, CO_2, HCOH) and some do (PFCs, CFCs, SF_6, He). Occupancy and consent should be considered if tracers are planned to be added, including communication of potential health effects, if any. If a large volume of any gaseous tracer is released by accident, it could potentially pose a risk of asphyxiation, so containers are best stored outside, where any unplanned releases will be rapidly diluted in the atmosphere.

Considerations for tracer selection include:

- **Perfluorocarbons (PFCs: such as perfluoromethylhexane and perfluoro-1,3-dimethylcyclohexane), chlorofluorocarbons (CFCs: such as Halon 1211, Halon 1301, SF_5CF_3, etc.) and SF_6**: For this suite of compounds, analytical sensitivity and selectivity are outstanding, so very small releases are sufficient to be detected. At very low concentrations, density and greenhouse gas emissions are negligible. Portable instruments can read down to 0.1 ppmv nearly continuously. GC/ECD can read down to 1 parts per trillion by volume (pptv) within about one minute. At very low concentration levels, outdoor air or indoor air may contain detectable concentrations, so tracers should be applied at a level with an acceptable signal-to-noise ratio.
- **Helium (He)**: Less of a concern for greenhouse gas emissions than CFCs, PFCs or SF_6. Portable detectors read down to 100 ppmv nearly continuously and laboratory analyses have similar sensitivity, so sensitivity is not low enough for some tracer applications. Methane and other hydrocarbons can cause interference, but outdoor air concentrations are usually too low to pose a background bias (~5 ppmv). Public acceptance is good compared to other tracers.
- **Carbon Dioxide (CO_2)**: Produced by building occupants and therefore a “natural” tracer, but there is a need to understand background conditions. Outdoor air averages ~300 ppmv of CO_2, while indoor air can contain up to ~1,200 ppmv of CO_2 in highly occupied buildings and needs to be determined on a site-specific basis. CO_2 can also be added to enhance resolution against background. The reporting limit is lower than outdoor average concentrations and is therefore not a limitation.
- **Formaldehyde (HCHO)**: Emitted from various building materials (e.g., particle board), so it is anthropogenic and often present in indoor air at detectable concentrations. HCHO would not be added intentionally because there are potential acute and chronic health effects. HCHO can be detected by electronic sensors down to about 1 part per billion by volume (ppbv) in about 30

minutes, so concentrations in mitigation system vent pipes can indicate the percentage of indoor air leaking across the floor slab.

- **Daughter Products**: Many VOCs of interest for VI degrade in the subsurface to form compounds that are not commonly found in consumer products or building materials, and could therefore be useful as tracers. For example, 1,1,1-trichloroethane degrades by hydrolysis to 1,1-dichloroethene (which is comparatively stable), which is not commonly detected in indoor air except as a result of subsurface VI, and can therefore be used as a tracer to indicate the VI pathway is complete. TCE degrades to cis-1,2-dichlorethene (c-DCE), which could be used in a similar manner, except that c-DCE also degrades, and in some cases, degrades faster than it is produced.
- **Sewer Gas Indicators**: Reduced sulfur compounds (RSCs) such as hydrogen sulfide (H_2S) and mercaptans in indoor air are an indication of sewer gas entry, and if sewers are known to contain VOC vapors, an RSC analysis could be a potential tracer for the VOCs.

Data Analysis and Interpretation

Correlation between tracers, indicators or surrogates and VOC concentrations helps to support their use as a guide to sample locations and times. The correlation should be evaluated using quantitative methods where possible. Analysis and interpretation of the tracer, indicator or surrogate data can then be used to select the locations and times of sample collection to minimize the risk of failing to capture the RME exposure point concentrations.

AERs measured using tracers are particularly useful in combination with mass flux (MF) measurements obtained by building pressure cycling or mitigation system mass removal rates, because indoor air concentrations attributable to VI (C_{VI}) can be calculated by dividing MF/AER. If C_{VI} is much less than the Indoor Air Screening Level (IASL), then VI is unlikely to pose unacceptable risks. MF and AER can be measured with lower variability than direct indoor air concentrations and lower variability leads to more conclusive determinations of potential risks.

Mitigation systems are designed to prevent VOC mass flux into the building at levels that could pose a potential risk. Vacuum is usually the primary performance parameter, but baseline fluctuations in the cross-slab pressure differential impose challenges to the signal-to-noise ratio and if the sub-slab material is highly permeable (e.g., granular fill), then flow can be substantial at vacuum levels too small to reliably measure. Measuring sub-slab ventilation rates is facilitated using tracers. Energy efficient mitigation systems also consider the amount of conditioned indoor air drawn across the floor slab, because the discharge of the system to outdoor air is essentially a waste of the energy applied to heat or cool the indoor air.

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